Chapin

TRANSACTIONS

OF THE

AMERICAN SOCIETY

OF

CIVIL ENGINEERS.

(INSTITUTED 1852.)

VOL. XX.

JANUARY TO JUNE, 1889.

NEW YORK:

PUBLISHED BY THE SOCIETY.

1889.

OFFICERS FOR THE YEAR ENDING DECEMBER 31, 1889.

MAX J. BECKER, *President.*

ALPHONSE FTELEY, E. L. CORTHELL, *Vice-Presidents.*

JOHN BOGART, *Secretary and Librarian.*

GEORGE S. GREENE, JR., *Treasurer.*

CHARLES B. BRUSH, ELIOT C. CLARKE, WALTER KATTÉ, ROBERT E. MCMATH, WILLIAM P. SHINN, *Directors.*

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

402.
(Vol. XX.—January, 1889.)

THE RELATION BETWEEN THE RAINFALL AND THE DISCHARGE OF SEWERS IN POPULOUS DISTRICTS.

By EMIL KUICHLING, M. Am. Soc. C. E.

WITH DISCUSSION.

The most important question which arises in the construction of a sewerage system whose function is also the removal of the surface drainage, is with regard to the amount of storm water that will find its way into the sewers; and therefore a brief review of the modes of solution adopted in different places may be of interest. The proportion of rainfall contemplated to be admitted into the sewers varies within wide limits and depends largely upon the intensity and duration of the rain, the relative impermeability and slope of the surface, and the facility with which the storm waters can be diverted into suitable natural channels, either directly from the roofs and street gutters, or indirectly by means of storm-overflows from the sewers; the element of initial cost is also of vast significance in determining the limits, and, by being too narrowly considered, frequently leads to reductions of drainage capacity which must be supplemented a few years later by the construction of special relief conduits, whose expense is often much greater than the original amount saved, together with accrued interest.

Arguments to the effect that a municipality can better afford to pay the damages caused by occasional sewer overflows, than to pay the interest on the additional expense involved by the provision of a more ample original capacity, are very common, but they never allude to the financial value of the annoyance, the sanitary dangers or the depreciation of property which always follows where the sewerage is defective. To quote from a report of a distinguished American engineer in regard to the improvement of the sewerage of a certain large city: "Your engineer has been aware for several years of the importance of improving the sewerage system; and the frequent complaints of householders in certain localities of the city have caused the most careful investigations to be made from time to time. The flooding of basements and cellars depreciates the value of property and endangers the lives of those occupying the flooded dwellings. The offensiveness caused by sewage flooding drives away tenants. The damage done to property cannot be estimated by the soiled goods and injured walls, but must be measured by the permanent prejudice created against the locality." These words are likewise applicable to many other cities than the one referred to, and hence, before accepting the cogent arguments which appeal only to the economical instinct, a careful analysis of the problem with special reference to probable future conditions should be made, even though it be attended with many complications and difficulties.

In the absence of definite experiments of their own, our American engineers have generally based their practice of sewerage upon the results of certain gaugings of the storm-discharge of a few sewers in London, which were made many years ago, and while the subject was still in its infancy. For some unaccountable reason, the details of these gaugings have not been published; and in reading the meager descriptions which are sometimes quoted, one is often at a loss to know whether the percentage of the rainfall so discharged refers to the maximum, or to the average for the entire period. The familiar case of the Savoy Street sewer, which is alleged to have given on June 20th, 1857, from an unusually heavy rainfall for London of 1 inch in one and one-fourth hours, a maximum flow of 0.34 cubic feet per acre per second, while the sewers of several adjacent and similar districts yielded only from one-fourth to one-seventh of this amount, is one of the few instances which are unambiguous in statement; but as some of these gaugings which were made by the London commission of 1857 have been shown to be

grossly inaccurate, the scientific value of the whole series is greatly impaired. Two different gaugings by Mr. Bazalgette, of the Savoy Street and Ratcliffe Highway sewers, for rainfalls of 2.90 inches in thirty-six hours and twenty-five hours respectively, refer specifically to the aggregate volume of rainfall discharged during said periods, and not to the maximum rate of discharge at any instant, the percentage so computed being given at 64.5 and 52.0 respectively. From these and a few other results, the distinguished engineers, Messrs. Bidder, Hawksley and Bazalgette, felt "warranted in concluding, as a rule of averages, that 0.25 inch of rainfall will not contribute more than 0.125 inch to the sewers, and that a fall of 0.40 inch will not yield more than 0.25 inch to the sewer." The two rainfalls mentioned are referred to as "the heaviest and most continued of the year 1857," and the two sewers are in the most densely populated portion of the city, the former "draining a locality strictly urban and of steep inclination," while the latter serves a "locality only moderately inclined." In the discussion of the Main Drainage of London, at a meeting of the Institution of Civil Engineers in 1865, Colonel William Haywood, the engineer to the sewer commissioners of that part of London called "The City," stated that in 1857, with a rainfall of 2.75 inches in thirty-six hours, the London Bridge sewer discharged 53 per cent. of said fall in the same time, and in 1858, with a rainfall of 0.24 inches in 1.5 hours, the same sewer discharged 74 per cent. of the fall; also that in June, 1858, "the Irongate sewer, which drains an area entirely paved and built over, discharged as much as 94.5 per cent. of a rain storm of 0.54 inch in five hours," while two months later the same sewer "discharged only 78 per cent. of a rainfall of 0.48 inch in 1.67 hours." Presumably these figures are the maximum percentages observed on these occasions, although nothing further than their extraordinary magnitude warrants such a conclusion, if the rainfall happened to be uniform in intensity. None of the reports, however, give any clue as to the character of the rainfall, the manner in which it was observed, or the location of the gauge, and hence the anomalies of measured percentage of discharge may be easily explained. Another familiar English authority on this subject is John Roe, who was for many years surveyor of the Holborn and Finsbury sewers, and who stated that during the continuance of a rainfall of 1.0 inch per hour, from 41 to 54 per cent. of the precipitation will reach the sewers, according to the amount of garden land or lawn upon the drainage area.

Upon the foregoing indefinite data principally, which may be found quoted more or less extensively in nearly every treatise on sewerage and in most of the elaborate reports, engineers have hitherto been content to rely; and it has thus come to be in some measure traditional that about 50 per cent. of the rainfall will run off from urban surfaces during the progress of the storm, while the remainder may follow at leisure. The greatest depth of rain for which provision should be made in planning sewers of American cities has likewise been commonly taken at one inch in an hour, "as its frequency, when compared with such falls as two and three inches in the same time, renders its consideration a more practical question; and the possibility of this rate of fall occurring for shorter intervals of time is so apparent from past observations on the sea-board and in the interior of the country, that we may regard it as a very proper maximum. It has been adopted as such in England, and, so far as we can learn, also in this country."*

This view still continues to prevail extensively, and but few engineers have ventured to step outside of the beaten path. On this basis, also, the sewerage systems of two large cities, which have long enjoyed the distinction of being the best works of the kind in the United States, have been designed. It was considered that, inasmuch as the English gaugings indicated that only from 50 to 75 per cent. of the volume of rainfall ever entered the sewers at all, the provision of a capacity for discharging a depth of one-half inch of rain over the whole area uniformly in one hour was very liberal, and would afford an ample margin for the contingencies of future growth. The fact was, however, soon established, that as these cities grew in population and in the number of buildings and improved streets, the main sewers proved to be inadequate to carry off the storm-water due to the heavy showers of comparatively short duration, and to remedy the evils resulting from deluged cellars in the flooded districts, special storm-sewers have been constructed and additional ones are contemplated in both cities. In one of these cities an attempt was made to restrict the amount of water admitted into the sewers by throttling the street inlets in such manner as to compel a portion of the rainfall to escape by flow through the gutters; but while the sewers may thus be somewhat relieved, the annoyance and damage caused by flooded streets is substituted, and may ultimately become an intolerable nuisance.

* "Sewers and Drains for Populous Districts," by Julius W. Adams, C. E., New York, 1880.

The same experiences have likewise been observed in a large number of other cities, both in this country and abroad, wherever rain storms of great intensity for relatively short periods of time are more or less frequent, and where the principles above set forth have been adopted in computing the size of main sewers unprovided with storm outlets. It is conceded that in the majority of these cases, notably in the two cities named above, no fault can be found with the execution of the sewerage works, and hence the failure must be attributed to the assumptions with regard to rainfall upon which the calculations are based.

The writer was long since impressed with the fact that during heavy showers the volume of water discharged at the mouths of several large outlet sewers in the city of Rochester, N. Y., appeared to increase and diminish directly with the intensity of the rain at different stages, but that a certain length of time was required in each case after the termination of a brief and heavy down-pour before the corresponding flood showed itself at the outfall; these floods, moreover, seemed to last about as long as the said showers themselves, and the conclusion was therefore reached that there must be some definite relation between these fluctuations of discharge and the intensity of the rain, also between the magnitude of the drainage area and the time required for the floods to appear and subside. The observations referred to were made casually, during showers giving about one-half inch depth of fall in from twenty to thirty minutes, and the flood discharge would begin about ten minutes after the commencement of the rain or of the component showers; in like manner the maximum flow would quickly diminish, leaving only a very moderate after-flow to continue for some time after the rain had ceased. Now, since the total proportion of the rainfall which is carried off by the sewers is of little consequence, whereas the absolute maximum flow during any short period of time is manifestly the controlling factor in estimating the efficiency of a sewer; and since this maximum appears to be governed by the rate of the rainfall during such short period, therefore the error made in the assumptions mentioned above must be due to the use of average rates of rainfall for an unduly long period of time, and the neglect of the rates for such short periods within which the surface drainage waters from all portions of the area may be concentrated at the outfall. This error becomes still more apparent, when we reflect that for a uniform rate of precipitation, the concentrated discharge from a given surface will become a maximum for the condition

hat the duration of such rate is equal to the time required for the water which falls upon the most distant points to reach the place of observation; or, in other words, that the entire area is contributing to said discharge; also from the fact that the heavy rainfalls in our latitudes rarely ever have uniform intensities for so long a period as one hour, and that few densely populated drainage areas contained within the municipal limits are so large as to require more than from fifteen to forty minutes for the full concentration of the storm-waters at some point of discharge. The conclusion is accordingly irresistible that the rates of rainfall adopted in computing the dimensions of a main sewer must correspond to the time required for the concentration of the drainage waters from the whole tributary area when small, or from so much thereof as will produce an absolute maximum discharge when the area is very large.

In justification of the prevalent practice, however, it is fair to say that the customary methods of observing the rainfall have hitherto prevented the development of the process just indicated, and have forced engineers to the use of average rates of precipitation deduced from periods of time scarcely ever less than one hour in duration. Thus the extensively and frequently quoted collection of rainfall statistics relating to Providence, R. I., which were made during forty years by Dr. A. Caswell, of that city, and published in the excellent report on the Sewerage of Providence, by J. Herbert Shedd, M. Am. Soc. C. E., in 1874, contains in the tables giving the record of three hundred and twenty-four storms, whose duration was carefully observed, only three cases where the rain lasted less than one hour, and in those instances the intensity of the rain did not exceed 1 inch per hour. The records were alleged to cover every appreciable rainfall which had occurred in said city during the interval between 1834 and 1874, and were regarded as perfectly reliable. A few of the storms observed in this long period were, however, so violent as to have induced Dr. Caswell to make special memoranda concerning them, and of this list only three entries specified the maximum rate of fall, as follows: September 28th, 1862, "nearly 2 inches of rain fell in the course of one hour;" August 16th, 1863, "very heavy thunder shower, 1.42 inches of rain falling in about twenty minutes;" June 17th, 1870, "storm lasting five hours, and giving 3.15 inches, nearly all of which fell between 12 M. and 1 P.M." Now, from these data the following condensed tables showing the relative frequency of rainfalls of different intensity per hour at Providence were con-

structed in 1874, and have since been widely copied by many distinguished writers in proof that great intensities of rainfall are exceedingly rare occurrences in our climate.

TABLE A.

Rate of rainfall in inches, per hour.	I. Number of storms during twenty-six years, from 1834 to 1860.	II. Number of storms during fourteen years, from 1860 to 1874.	III. Number of storms during forty years, from 1834 to 1874.
0.25, or a little less..	131	98	229
0.33, or a little less..	18	9	27
0.40, or a little less..	9	2	11
0.50, or a little less..	7	10	17
0.60 to 0.62	8	5	13
0.67 to 0.70	3	3	6
0.75 to 0.80	3	2	5
0.87 to 0.90	4	1	5
1.00 to 1.12	1	2	3
1.20 to 1.40	0	2	2
1.52 to 1.83	1	2	3
2.00 to 3.15	0	3	3
Totals..	185	139	324

The inferences that have been drawn from the foregoing table, even long after it was discovered that some of the main sewers in Providence and other cities had repeatedly proved to be incapable of removing the storm drainage, are as follows: 1. That out of three hundred and twenty-four large rainfalls in forty consecutive years, only three gave rates of 2 inches or more per hour; six gave rates of more than 1.5 inches per hour, and eleven gave rates of 1.0 inch or more per hour; and 2. that therefore a rainfall of 2.0 inches or more per hour can reasonably be expected to occur only once in thirteen years, while one of 1.5 inches per hour may happen once in about seven years, and one of 1.0 inch or more per hour about once every four years. Such inferences are, however, certainly unwarranted by the records derived from automatic rain gauges, which indicate that heavy rates for short periods of time are very common occurrences; and it is needless to say that even casual observation of the rainfall in the principal cities of the New England and Middle States prevents the application of the aforesaid inferences to intelligent sewerage work. To give reasonable assurance that special storm sewers will not be required in a district within a few years after the development of the suburban area has progressed, accordingly involves the adoption of a much higher rate of precipitation than one inch per hour when the

time required for the concentration of the surface discharge is much less than one hour, as is generally the case.

In order to guard against engorgements of the sewers, the exact duration and depth of water of both the entire storm and its variable showers must be known, as it frequently happens that during a rainfall which lasts one or more hours without intermission, the intensity of the precipitation will change greatly from time to time, thus causing the entire storm to resemble a series of hard showers connected together by intervals of mere drizzle. The average intensity of such a storm is of comparatively little consequence in dealing with the important problem of maximum flow in sewers, since it may be only one-third or one-fourth of the rate of fall which has occurred during some one of the component hard showers, and which would properly govern an engineer in fixing the dimensions of a sewer. Hence when the records of a certain rainfall do not show that the rate of precipitation has been practically uniform throughout the entire specified duration, the results obtained by gaugings of the corresponding sewer discharge will be utterly misleading, and their indiscriminate use may give rise to errors of design. which may entail serious consequences.

The usual rainfall records merely give the total depth of water precipitated during certain regular intervals, such as 24, 12 or 6 hours; another very limited class of records indicate the approximate duration of the showers and the depth, the time in such cases being occasionally estimated when the attention of the observer at the beginning or end of the rain has been diverted by other matters; while a third class of records, which are, however, rarely kept outside of the most important meteorological stations, give the rates of fall at all times during the entire continuance of the rain. For sewer-discharge computations, the first of these three classes is almost entirely worthless, and their collection may accordingly be considered as a sheer waste of time; the second has much value, but must be used cautiously, especially when the rainfall happens to be of longer duration than about thirty minutes; the third class is by far the most valuable, and should be kept in every growing city where sewerage works exist. The best method of securing such data is from a number of self-recording rain gauges located in different parts of the municipal area, since a heavy shower may pass over a city in such manner as to deliver great quantities of water in one section, while another portion may receive only a light sprinkling. Cases of this kind

have frequently been observed in Rochester, N. Y., particularly during the past year, when opportunity for comparison was afforded by the records of the two gauges maintained by the writer, and those of the United States signal service and the city water works department, the four similar instruments being located at a distance of about one mile apart. It is greatly regretted that none of these gauges were of the self-recording type; but the great expense connected with the purchase and maintenance of automatic gauges precluded the writer from availing himself of such instruments, and as a consequence, it was found too late that only a few of the many records thus obtained could be used with reasonable certainty.

The numerous observations and measurements of the rainfall and contemporaneous flood discharge of a number of large sewers which are given in full detail below, will doubtless suffice to point out the necessity of securing the rainfall data needed in the consideration of the discharge from surfaces by means of automatic and self-registering devices, instead of trusting to the judgment of even the most careful and well-trained observers. Many other similar instances could be selected from the mass of material thus obtained in the course of the past year; and wherever such experiments are repeated, it is now urgently advised to make use of a large number of automatic rain gauges scattered about on the various separate drainage basins and located not more than about 1 500 feet apart, if only a single season be allowed for the collection of statistics. Most of the showers, moreover, occur during the night-time, and with the usual appliances the records for such cannot be secured unless two sets of observers are employed. Measures should also be taken to cause every Signal Service station in the cities of our country to be equipped with the best automatic gauges, and to have the results thus obtained carefully tabulated, in order that communities may be spared the great outlay of soon reconstructing sewers whose dimensions were based upon the deceptive records of rainfall as heretofore kept.

That the subject is already beginning to receive some recognition, is shown by the recent publication of the data derived from the self-registering rain gauge at Washington, D. C., in response to a request from the superintendent of sewers of that city; and, as the information thus elicited serves to indicate the striking differences in the rate or intensity of the rainfall during the progress of a heavy storm, the following quotations from the circular of the Chief Signal Officer, issued

about one year ago, may be of interest: "The observations (referring only to Washington) cover a period of seventeen years, from January, 1871, to December, 1887, in which time rain or melted snow has been recorded 1 543 times. The rainfalls exceeding 1 inch in depth number 192, of which 37 yielded 2 inches and upwards in depth for the entire duration of the storm. Precipitation exceeding 2 inches occurred four times in August and six times each in June, July, September and October, while they were rare in other months, and never happened in February. The heaviest fall from a single storm was 5.80 inches in nineteen hours on July 29th and 30th, 1878. Of equal and perhaps greater importance than the amount recorded during a single storm is the rate which falls in any single hour. Assuming that a less rate than 1 inch per hour is not especially important, examination was confined to those cases in which the rate was greater. Sixteen such cases have occurred, as shown in the following table:

TABLE B.

Date.	Amount in Inches.	Time.		Average Rate of Fall per hour. Inches.	Maximum Rate of Fall per hour at any time. Inches.
		Hours.	Minutes.		
July 3d, 1871	1.13	0	30	2.26	2.26
July 18th, 1871	0.83	0	20	2.49	2.49
September 25th, 1872	1.50	1	00	1.50	8.00
August 18th, 1875	1.20	1	00	1.20	2.40
August 29th, 1875	1.30	1	00	1.30	1.30
October 23d, 1875	1.40	1	00	1.49	2.50
June 22d, 1877	1.08	1	00	1.08	2.00
July 28th, 1877	1.20	1	00	1.20	3.00
July 29th, 1877	1.42	0	26	3.24	3.24
October 4th, 1877	1.49	1	00	1.49	6.00
July 2d, 1884	1.12	1	00	1.12	3.00
November 24th, 1884	1.00	1	00	1.00	2.00
July 26th, 1885	0.96	0	06	9.60	9.60
October 29th, 1885	1.20	1	00	1.20	2 40
June 24th, 1886	1.10	1	00	1.10	3.00
July 26th, 1886	1.80	1	00	1.80	6.00

Thus it appears that on two occasions 1.50 inches fell in one hour, and on one occasion 1.80 inches fell in the same time; but it will be seen that in all of these three cases, the maximum rate was far in excess of the average rate, the table showing that for short periods of time the rain then fell at rates of 8 inches and 6 inches per hour. The greatest

rate recorded, however, was the extraordinary one of 9.60 inches per hour, which fell on July 26th, 1885, but lasted only six minutes."

It may be remarked that for the purpose of determining the percentage of rainfall discharged from urban surfaces, the maximum rates of precipitation for values less than 1 inch are also of much importance, as the difference in such percentages for various rates of fall may thereby be ascertained. The exact duration of the maximum rates, moreover, should likewise be carefully tabulated, since in small districts the surface drainage may perhaps be fully concentrated before the heaviest portion of the shower has ended, in which event the corresponding rate must be used in computing the said percentage. Concerning the latter, it is reasonable to suppose that the same should vary in some degree both with the intensity of the rainfall and its duration, in all cases where this time is equal to or exceeds the period required for the drainage from the most distant points of the area to reach the point of observation in the sewer. Thus the percentage of discharge from a given district due to a uniform rate of 1.0 inch should be somewhat greater than that derived from a similar rate of 0.5 inch in the same length of time, and it should also increase with the duration of the rain when falling uniformly. So far as can be learned, no successful attempt has yet been made to compute these differences in rates of discharge, which are of so much importance in works of municipal sewerage or drainage, and it is a source of much regret to the writer that the lack of the said data prevented an examination of this nature in connection with his work during the past year.

In a paper on the maximum rates of rainfall by Desmond Fitz Gerald, M. Am. Soc. C. E., of the Boston water works, printed in *Engineering News* of May 31st, 1884, the author refers to some of the heaviest rainfalls which occurred in the vicinity of Boston for a series of years. The most noteworthy of these is the storm of August 16th, 17th, 18th and 19th, 1879, which yielded a total depth of 6.23 inches, and of this amount 3.43 inches fell in 10½ hours on the 18th, the maximum being at the rate of about 1.0 inch per hour. The greatest intensity of rainfall observed was recorded July 20th, 1880, when 0.75 inch fell in thirteen minutes and 1.17 inches in thirty minutes, thus giving rates of 3.46 and 2.34 inches per hour respectively. Maximum intensities ranging from 1.5 to 2.0 inches per hour and lasting from eight to forty-five minutes seem to be usual attendants upon nearly all the storms whose diagrams are exhibited;

and as such durations will generally admit of the concentration of the drainage from small urban districts, the importance of providing for such falls will at once be recognized.

While the imperfect rain records for Rochester and the surrounding territory do not indicate that intensities of more than 1.5 inches per hour are of frequent occurrence, yet it is barely possible that greater rates would be discovered if self-registering gauges were used. It may, therefore, be of interest to note a few more of the heavy rains which have been observed at other places. At St. Louis, the following were recorded in 1884: 5.05 inches in $1\frac{1}{4}$ hours, 5.22 inches in three hours, 6.17 inches in five hours, and 7.55 inches in twenty-nine hours; at Providence, R. I., 4.49 inches fell in one hour on August 6th, 1878, of which amount 3.50 inches came in thirty-six minutes, thus giving a rate of 5.85 inches per hour; and on August 13th, 1888, a storm occurred which gave 3.10 inches in eight hours, the maximum intensity being 3.75 inches per hour; at Leland, Miss., a rainfall of 11.5 inches occurred on August 15th, 1888, and was followed on the next day by one of 9 inches; at Waltham, Mass., 5.63 inches in three hours was recorded on August 21st, 1860; during a heavy storm over eastern Connecticut in August, 1874, a depth of 12 inches of water fell in forty-eight hours, and 5 inches in four hours; another great storm in Connecticut, and which extended over the New England States generally, occurred on October 3d and 4th, 1869, when the following depths were recorded at different localities within about thirty hours: 8.43 inches at Hartford, 8.44 inches at Colebrook, 9.37 inches at Middletown, and 12.35 inches at Canton, the greatest rate then recorded being 4 inches in two hours. The continuous rain in New England on February 10th to 14th, 1886, however, surpassed most of the previous ones in both intensity and duration, as well as disastrous consequences. From the accounts of this storm given by Professor W. Upton, in Volume VII of *Science*, and by the commission of engineers consisting of James B. Francis, Eliot C. Clarke and Clemens Herschel, in their report to the city of Boston on the prevention of floods in the Valley of Stony Brook, it seems that the greatest fall occurred on the 12th, when 6.66 inches fell in twenty-four hours at New London and a total of 8.93 inches in fifty-eight and one-half hours; the same storm also yielded the following depths at other cities: 3.41 inches in forty-nine and one-half hours, with 2.99 inches in twenty-four hours at New York; 8.13 inches in seventy and one-half hours, with 5.65 in

twenty-four hours at Providence; 5.62 inches in fifty-five hours, with 4.45 in twenty-four hours at Boston, and 4.78 inches in seventy-seven hours, with 3.30 in twenty-four hours at Newburyport.

With regard to the extent of territory that may be covered by a heavy shower at any instant of time, observations show exceedingly wide variations. The storm area in our latitude is commonly several hundred miles in diameter, and occasionally exceeds two thousand miles in diameter, but the rain area is usually very much less, especially in the case of sharp thunder storms, where sometimes only a few square miles of the earth's surface are covered by the rain cloud. The writer has frequently noticed both the passage and the approach of such discharging clouds, and estimates that for a precipitation lasting about 15 minutes, the least area covered by the densest portion of the rain, as viewed from a distance, is about 4 miles in length and 1½ miles in width, thus giving an area of about 6 square miles. For shorter durations the area may be correspondingly smaller; but in general, the clouds which furnish rainfalls that greatly concern the capacity of sewers are considerably larger in extent than any single drainage area within ordinary municipal limits. On the other hand, to point out how great an area may be covered by a single storm, the following data given by James B. Francis, M. Am. Soc. C. E., and Professor W. Upton may be cited: For the storm of October 3d and 4th, 1869, the area on which 8 inches or more fell had a length of 65 miles, with an average width of 28 miles; the area on which 9 inches or more fell was about 50 miles long by 21 miles wide; the area on which 10 inches or more fell was about thirty-four miles long by 15 miles wide; and the area on which 11 inches or more fell had a length of about 20 miles, with an average width of 9 miles; similarly, for the storm of February 10th to 14th, 1886, the area on which over 8 inches of water fell was 750 square miles; that on which from 6 inches to 7 inches fell was 1 500 square miles; and that on which from 4 inches to 5 inches fell was 2 750 square miles. These areas were computed by plotting the observed depths of rain-fall at different places on the same day upon a map, and then drawing the contours showing the lines of equal depth; from the map thus prepared the required areas may then be easily determined.

Numerous other instances of severe rainfall might be cited; but the foregoing will doubtless suffice to exhibit not only the exceedingly variable character of the rate and duration of heavy storms, but also the necessity of carefully studying the data afforded by each particular

locality. As already stated, to secure a reliable estimate of the amount and rate of precipitation in Rochester, simultaneously with gaugings of the maximum flood-discharge of all the principal outlet sewers in the eastern portion of the city, two ordinary rain gauges of special design and carefully rated were procured and maintained for the past year by the writer, and placed in charge of thoroughly competent observers. Between the sites of these gauges at two points on the west and east sides of the city, the United States Signal Service station is located, while the rain gauge maintained by the Water Department of the city is situated about 1¼ miles to the south. Four observations of the same rain at as many different points thus afforded the means of comparison with respect to intensity and quantity, while a careful timing and general observation of the rainfall, as viewed from the writer's office, secured ma y checks upon the records of those in charge of the gauges, and furnished clues to some of the numerous anomalies of discharge which were subsequently found. To obtain the depth, the water collected by three of these gauges was carefully weighed on delicate balances, and from this weight the corresponding volume was derived; hence, as the area of the 9-inch opening presented to the rain was accurately known, the resulting depth was easily found. At the Signal Service station, on the other hand, the depth is obtained by direct measurement with a graduated rod in a vessel considerably narrower than the gauge orifice. In this manner of gauging, the rate at all times during the progress of a storm cannot be secured, and with only one set of observers, many showers which happen during the night-time must necessarily be passed without specific record. The data thus derived can accordingly not be regarded as giving a perfectly correct view of the rainfall, but it is the only one which is here available.

In order to ascertain the frequency and intensity of heavy showers in this portion of the State, the writer was kindly supplied by the Chief Signal Officer with the statistics relating to rainfalls of more than 0.25 inch per hour collected at the stations in Rochester, Buffalo and Oswego from 1870 to 1888 inclusive; by the authorities of Cornell University with similar statistics relating to Ithaca from 1879 to 1888 inclusive; and by the chief engineer of the Rochester water works, with the records kept at Mount Hope Reservoir and Hemlock Lake from 1878 to 1888 inclusive. All of this information was arranged by months in tabular form; but to exhibit the essential facts in more con-

venient shape, they have been summarized in the following table, which gives the recorded number of rains of different intensities during the cold and warm seasons, together with the deduced average number of times per year that a rain of the specified intensity has been observed at the several localities mentioned.

TABLE C.

Rate of Rainfall, inches per hour.	Number.		Total Number.	Number of years' observation.	Locality.	Average Number per year.
	From November 1 to April 1.	From April 1 to November 1.				
0.20 to 0.50	12	71	83	18	Rochester.......	4.61
0.50 to 0.75	2*	24	26	18	"	1.44
0.75 to 1.00	0	9	9	18	"	0.50
1.00 to 1.25	0	6	6	18	"	0.33
1.25 to 1.50	0	4	4	18	"	0.22
1.50 to 1.75	0	2	2	18	"	0.11
1.75 to 2.00	0	1	1	18	"	0.05
2.00 to 3.00	1†	5	6	18	"	0.33
0.20 to 0.50	0	42	42	15	Hemlock Lake ..	2.80
0.50 to 0.75	0	9	9	15	" " ..	0.60
0.75 to 1.00	0	6	6	15	" " ..	0.40
1.00 to 1.25	0	2	2	15	" " ..	0.13
1.25 to 1.50	0	2	2	15	" " ..	0.13
1.50 to 1.75	0	1	1	15	" " ..	0.07
1.75 to 2.00	0	1	1	15	" " ..	0.07
2.00 to 3.00	0	1	1	15	" " ..	0.07
0.20 to 0.50	1	46	47	17	Buffalo..........	2.76
0.50 to 0.75	0	16	16	17	"	0.94
0.75 to 1.00	0	2	2	17	"	0.12
1.00 to 1.25	0	4	4	17	"	0.24
1.25 to 1.50	0	1	1	17	"	0.06
1.50 to 1.75	0	1	1	17	"	0.06
1.75 to 2.00	0	0	0	17	"	0.00
2.00 to 3.00	0	3	3	17	"	0.18
0.20 to 0.50	0	17	17	17	Oswego	1.00
0.50 to 0.75	0	9	9	17	"	0.53
0.75 to 1.00	1‡	0	1	17	"	0.06
1.00 to 1.25	0	2	2	17	"	0.12
1.25 to 1.50	0	2	2	17	"	0.12
1.50 to 1.75	0	1	1	11	"	0.06
1.75 to 3.00	0	0	0	17	"	0.00
0.20 to 0.50	1	21	22	9	Ithaca...........	2.44
0.50 to 0.75	0	15	15	9	"	1.66
0.75 to 1.00	0	3	3	9	"	0.33
1.00 to 1.25	0	2	2	9	"	0.22
1.25 to 3.00	0	0	0	9	"	0.00

It should be remarked that the figures relating to the number of rains given in the above table are not worthy of much credit, owing to the absence of self-registering devices. For example, three of the six rains at Rochester, with rates of from two inches to three inches per

* March, 1881, and November, 1885, lasting one hour twenty minutes and fifteen minutes respectively.

† March, 1880, lasting only five minutes.

‡ November, 1876, lasting twenty minutes.

hour, occurred in 1888 and were all obtained from the gauges maintained by the writer; hence, instead of such a rain—which caused serious overflows in nearly every sewer wherein observations were taken—occurring only once in three years, as per table, it has in fact occurred three times in one year, and twice on the same day! Furthermore, it is the writer's firm conviction that at least two rains of similar intensity occurred in 1887 in said city, no record of which is contained in said table; and he has an equally strong conviction that if proper automatic gauges had been in use at the two stations in said city, the list of heavy showers would have been enormously increased during the course of the past eighteen years. Doubtless the same might be said of the other stations named, and hence the necessity for the use of better apparatus in obtaining these important statistics. Wherever much reliance has been placed upon such data as exhibited in Tables A and C, sewer engorgements and cellar floodings have, curiously enough, soon followed in the wake of the sewerage system, and large outlays are demanded for the construction of relief conduits when direct storm overflows cannot be provided.

The important question is with reference to the duration of the heavy rainfalls which cause the capacity of the sewers to be exceeded and thus give rise to damage in the adjacent cellars. An attempt to solve this problem for the locality of Rochester with the data afforded by the aforesaid local rainfall tables was made in the following manner; and while the said data are doubtless deficient, yet they constitute the only available means of reaching any reasonable conclusion in the premises: The intensities of all these rainfalls, or the rates of precipitation in inches per hour, were first computed from the given total depth and time, and were then plotted as ordinates with the corresponding actual durations of the rain as abscissas; a multitude of points on the diagram was thus obtained, each one representing by its location a different rate of fall for definite periods of time; and since the rains of relatively light intensity were far more numerous than the heavy ones, these points were much closer together in the lower portion of the diagram than in the upper part. Now by connecting the successive highest points by straight lines an irregular envelope, or line enclosing all of the remaining points, will be obtained, and the ordinates of such envelope will represent the probable maximum intensities of the rainfall in this locality for the corresponding abscissas, or periods of time. A closer

examination of the diagram, however, shows that by omitting only a very few of the highest points, the said envelope may conveniently be represented by two straight lines which form an abrupt angle with each other at a point corresponding to an intensity of about 0.87 inch and a duration of about 1.0 hour. The line to the left of the point of intersection is quite sharply inclined, while that to the right is more nearly horizontal, thus showing very clearly that the maximum uniform intensity of the rainfall diminishes rapidly as its duration increases from a few minutes to one hour, and that for rains of uniform intensity lasting more than one hour the rate of diminution is comparatively slow. The diagram is shown on Plate I.

To express the relations of the probable maximum intensity of the local rainfall to its duration in mathematical terms, let t denote the duration in minutes, and y denote the maximum intensity in inches per hour; for periods less than one hour we will then have:

1) .... $y' = 3.73 - 0.0506t,$

while for periods longer than one hour and less than five hours we have:

2) .... $y'' = 0.99 - 0.002t.$

There is, however, more or less doubt about the accuracy of the data in the said tables, and it may be argued with much force that under the circumstances it would be preferable to consider averages rather than extremes; also, that for application in Rochester, the data relating to that city alone should be taken into account, especially since the same appear to be more numerous and in much greater detail than the others. Proceeding on this assumption, and grouping together such of the twenty rainfalls of greatest intensity (ranging from 0.86 inches to 3.17 inches per hour) as have equal durations, we find that the averages for periods less than one hour will be much less than the values obtained from equation (1) above; and that the values derived from the following substitute for said equation will agree quite closely with such averages for periods ranging from fifteen minutes to one hour:

3) .... $y' = 2.10 - 0.0205t.$

The results of the computations of y' from equations (1) and (3) for different times t, as well as the aforesaid averages of the observed intensities, are arranged in the table on the next page.

The results thus found are generally much larger than those given by the empirical formulas in common use, which predicate a rainfall of not more than one inch per hour for drainage areas of all magnitudes.

TABLE D.

Duration of Rain in Minutes (t).	Computed Intensity (y') from Eq. 1.	Computed Intensity (y') from Eq. 3.	Average of Observed Intensities.	Number of such Observations.
5	3.48	2.00	3.00	1
8	3.33	1.94	2.88	1
14	3.02	1.81	3.17	1
15	2.97	1.79	1.73	4
20	2.72	1.69	1.95	2
25	2.46	1.59	1.70	2
30	2.21	1.49	1.43	2
35	1.96	1.38	1.32	1
40	1.70	1.28	1.40	2
45	1.45	1.18	1.39	1
50	1.20	1.07	....	0
55	0.95	0.97	0.95	1
60	....	0.87	0.86	1

It should be distinctly stated that no great accuracy or general applicability is claimed for the above-mentioned Equation 3, which is of the most importance in the computation of dimensions for large sewers, nor for the data upon which said equation is based; it is merely an effort to utilize the only available records of the local rainfall in a rational manner, and to remove the subject of urban sewerage somewhat further from the realm of vague conjecture.

The foregoing method of ascertaining the probable maximum intensity of the rainfall of any particular locality was subsequently found to be practically identical with that adopted by Professor F. E. Nipher, of St. Louis, in the consideration of the rainfall of that city, a brief account of which is contained in Vol. IX of *The American Engineer*, Chicago, 1885. On plotting the records of the heaviest rains observed at St. Louis during a period of forty-seven years in the same manner as described above, the envelope enclosing all the points was found to be an equilateral hyperbola whose equation Professor Nipher considers to be: $y\,t = 6$, the duration t being taken here in hours instead of minutes. This formula represents the statement that six inches of rain may fall in one hour, or that it may be spread over a greater number of hours; so that if the heaviest rain lasted uniformly for two hours, the maximum rate would then be $y = 3$ inches per hour, and 1.5 inches per hour for four hours, etc. An examination of the rainfall diagram for Rochester indicates that the envelope might possibly be an hyperbola, but not an equilateral one.

The famous hydrological studies of the basin of the River Seine, by Belgrand, caused the Parisian engineers to adopt a maximum rainfall of

1.77 inches in one hour as a governing factor in proportioning the modern sewerage works of the French capital. For the outlet sewers of large districts, it is assumed that about one-third of this depth is collected or concentrated during the progress of the rain and flows off rapidly, while the remainder is retarded in its flow and is lost by evaporation and absorption. To compare the foregoing maximum of 1.77 inches with a similar maximum that might be selected for some other city, such as Rochester, on the basis of the average annual rainfall, it may be mentioned that the average yearly rainfall of Paris is only about 23 inches, while that of Rochester is about 33.5 inches, so that the proportionate maximum rate for the latter city would be 2.60 inches per hour. In anticipation of comment, however, the writer would remark that the available observations of the local rainfall do not give so high an average, and that a rate of such magnitude would apply only to an extremely small district; or, in other words, would prevail for only a very short time, as fully pointed out above.

In referring to the Parisian practice in an excellent article in the *Annales des Ponts et Chaussées* for February, 1888, D. E. Mayer, of the French engineer corps, advises the adoption of Belgrand's estimate, as given above, for like conditions of rainfall, climate and proportional amount of impervious surface, in other large cities, "deducting, however, in the computation of the tributary drainage area, all gardens and other cultivated or vacant land." In smaller cities, "where the density of population is less, the proportion of such garden and other open land is greater than in the larger towns, and hence a much larger proportion of the rainfall would be lost before reaching the sewers, while the ordinary discharge per acre also diminishes with said density." It is therefore probable that the proportional discharge adopted in Paris may likewise be applicable in minor municipalities when it becomes necessary to remove the surface drainage.

In German cities the recent practice appears to be similar in general theory to that just outlined for French towns, only that the maximum rainfall is usually taken at a much lower figure. Thus, for Berlin such rainfall is assumed at only seven-eighths of an inch per hour, one-third thereof reaching the sewers while the rain is falling. The mean annual rainfall is, however, only 22.3 inches, and it is claimed that a greater intensity than about 1.0 inch per hour was never observed there. Under such conditions a liberal provision appears to have been made.

For Vienna, the maximum rainfall was assumed at about 1.10 inches per hour, and three-eighths thereof is considered to reach the sewers in the same time. For Frankfort, Munich, Stuttgart and a number of other cities, variable allowances were made by the designers of the sewerage systems, but in all cases relief was assured by a sufficient number of storm overflows into the rivers. It is, however, quite noticeable, from the more recent reports and works on sewerage, that higher intensities of rainfall than heretofore considered admissible must be adopted for urban districts in which storm outlets are impracticable.

For example, when the sewerage of Stuttgart was designed in 1874, it was assumed that not more than 27.5 per cent. of any rainfall would reach the main intercepting sewer during the continuance of the storm; but the city engineer, in a work published in 1886, states that such an assumption is justifiable only when the drainage area includes large tracts of vacant land, and that his experience indicates a proportion ranging from 50 to 70 per cent. of the rainfall, according to the density of population and the condition of the street pavements. In his report on the sewerage of Königsberg, in 1883, the distinguished engineer, Wiebe, recommends that provision be made for admitting 50 per cent. of a maximum observed rainfall of 2.89 inches per hour into all sewers in the high level district of the city, where no storm overflows could be obtained; he also considers that very little of the water runs off from moderately inclined gardens, lawns and vacant land into the sewers during the first hour of the storm, and hence that only the area actually covered with buildings and pavements need be considered; for the city mentioned he estimates this relatively impervious area at from 42.3 to 54 per cent. of the total drainage area, according to the particular districts considered. To compensate for any contributions from the garden and land surface thus omitted, the roof and pavement surface is regarded as fully impervious, and taking this latter on an average at 50 per cent. of the whole, with one-half of the rainfall running off, it will be seen that by this procedure provision for about one-fourth of the maximum rate of precipitation is made in the sewers. For Mayence, the elaborate report of City Engineer Kreyssig, published in 1879, contained similar statements to the effect that all sewers not provided with storm-outlets should be capable of removing the accumulated surface drainage due to the heaviest observed storms without becoming surcharged; and as the rainfall records of that city indicated that the depth

yielded by an extraordinary rain, such as occurs only once every few years, is about 1.60 inches per hour, Kreyssig considered this limit as the lowest which could reasonably be adopted for said locality, and that at least 50 per cent. of such a fall would reach the sewers within one hour from the old and more densely populated districts. With respect to the general character of the surface in European cities, it may be remarked here that the local density of population in the older districts is often very great, the average being about 291 people per acre in Stuttgart and 162 in Mayence. Furthermore, that every street is well paved, and that very little of the surface is occupied by gardens or lawns, so that an estimate of only 50 per cent. of the rainfall is by no means large.

On the other hand, in support of the common theory of English engineers that heavy rainfalls of comparatively short duration do not yield such large percentages of discharge from urban surfaces, City Engineer Mank, of Dresden, published in the *Deutsche Bauzeitung* for 1884 the following observations: During a rain which lasted twenty-five minutes and fell at the rate of 1.96 inches per hour, the outlet sewer of a certain district of 326.7 acres in Dresden was noticed to be running completely full; the said district contained 49.1 acres of surface in the old portion of the city, which was almost entirely covered with roofs and pavements, 164.2 acres of closely built up territory in the new portion, and 113.4 acres of semi-suburban surface; considering the first-named component area as fully impervious, the second as giving 67 per cent. of impervious surface, and the third as giving only 34 per cent. of such surface, we would have an aggregate of 197.7 acres, or 60 per cent. of the whole, as practically impervious, and from which all of the rainfall should be delivered rapidly into the sewers; at the said rate of 1.96 inches per hour the water fell on said 197.7 acres at the rate of 387.5 cubic feet per second, while the outlet sewer was alleged to be discharging only 83.9 cubic feet per second; and hence it was inferred that a rain of the great intensity mentioned could yield to the sewers only about 21.7 per cent. of the precipitation on the estimated impervious surface, or only 13.1 per cent. of that on the total area. Exception to the aforesaid estimate of impervious surface might readily be taken as being excessive, and the percentage of discharge might thus easily be increased; the rain may also have been of much less intensity on the particular drainage area than it was at the location of the gauge, since in storms of such great violence the observations of the writer prove

conclusively that a difference of one-half or even one-fourth of a mile may make an enormous reduction of average intensity during so short a period as twenty-five minutes. The description given, furthermore, does not state specifically that the said discharge was the absolute maximum during the progress of the shower, and that the water did not rise higher than stated either before or after the time of the observation; but the principal exception that the writer makes to the foregoing is that the measurements of maximum flood-discharge by automatic gauges in a number of sewers in this city during the past year, firmly establish the fact that the percentage of discharge for such a shower is very much greater than as computed above; and in proof of the validity of this assertion, the following instance may here be cited:

Between 7.25 P.M. and 8 P.M. on May 9th, 1888, a violent thunder storm, giving 0.767 inches of rain in thirty-five minutes, or a rate of 1.315 inches per hour, passed over the city from southwest to northeast. The writer had an opportunity to see the approach of the cloud from an elevated position, and to notice that one of his rain gauges lay directly in the track of the densest rain, while the other was near the edge of the shower. The latter yielded a depth of only 0.203 inches, and hence a rate of 0.348 inches per hour, its distance from the former being about two miles. Now the maximum discharge of the Clifford Street and Avenue B outlet sewer, whose drainage area was seen to be traversed by the heaviest portion of this rain, was found to be 73.3 cubic feet per second from a tributary total area of 356.9 acres, in which the average density of population does not exceed 20 per acre, and in which there are only a very few macadamized roadways, all the rest of the streets having simply natural earth roadways, with graded gutters and plank sidewalks; the vacant land, moreover, is largely of a gravelly character, so that little was contributed therefrom to the sewers. About three-fourths of the said territory is well drained, nearly every street therein being provided with a sewer, while the remainder is to a great extent undeveloped agricultural land. The dwellings are principally small cottages, many of which are not yet connected with the sewers. According to the results obtained from estimates of the proportion of impervious surface on different classes of urban territory, the aggregate impervious surface should here be about 20 per cent. of the total area of 356.9 acres; but in view of the fact that such estimates predicated much better conditions of surface than are actually presented on this territory, the percentage

of impervious surface should be reduced to not more than 15, whence we would have about 53.6 acres of such surface from which all of the water would reach the sewers.

On this basis, and with a rate of rainfall of 1.315 inches per hour, the maximum sewer-discharge should be 70.5 cubic feet per second, which is a close agreement with the observed discharge of 73.3 cubic feet. To complete the data, it may be further remarked that the time required for the concentration of the surface drainage from the most distant points of the area to the point where the said maximum flow was registered is about thirty-four minutes, the average velocity of flow in the sewers being about 4.4 feet per second when nearly full, and their grades ranging from 1 in 47 to 1 in 910, with an average of 1 in 150. The said storm thus lasted long enough to cause the whole area to contribute to the flood discharge, which yielded a maximum of 15.6 per cent. of the rainfall on a territory which may fairly be classed as rural in comparison with the above described district of nearly equal magnitude in Dresden. Under the circumstances, therefore, the writer is convinced that there must be some serious error in the aforesaid data relating to Dresden, from which a maximum discharge was deduced of only 13.1 per cent. of a storm having an intensity of 1.96 inches per hour, lasting twenty-five minutes, and falling upon a well-sewered urban area, of which 60 per cent. is regarded as impervious.

On the strength of these latter data Mr. Mank built up a series of sewerage tables for the use of municipal engineers, which have been extensively copied into recent reports, notably those relating to Berlin and Wiesbaden. The professional eminence of the authors of these two reports is such as to have added greatly to the value and reliability of these tables, and it is only after abundant proof from the results of his own carefully conducted gaugings was afforded that the writer now ventures to call them in question. Their manifest error is attested by a number of other experiments similar to the one just described, and which will be given in detail below, also by the observations made in the past by English and American engineers. In view of these facts it is hardly worth while to consider further this method of computing the dimensions of outlets for districts of ordinary size.

The relation between the magnitude of a drainage area, the surface discharge, and the time required for the concentration of such discharge, has long been recognized in a general way, but does not appear to have

been very definitely expressed. In a paper by General O'Connell on "The Flood Discharge of Rivers," published in Volume 27 of Proc. Inst. C. E., the principle is stated as follows: "When water falls in the shape of rain on any solid surface, whence it afterward flows off, it forms its own drainage vehicle. It produces over that solid surface a certain depth of water with a certain superficial fall or slope toward an outlet; these two conditions, depth and surface slope, being necessary to secure flow. Should the solid surface be at all absorbent, the rain has to furnish the quantity of water necessary to saturate it. While the drainage vehicle is forming and having its capacity increased, the water is flowing off the surface less rapidly than it falls upon it, and, should the rain cease before it has completed its own drainage vehicle, the rate of discharge from the surface upon which it falls will never equal the rate at which the rain has fallen upon it. It is only when the time necessary for this preliminary operation of forming its own drainage vehicle has elapsed, that the water flows off from a surface as rapidly as it falls upon it. The time required increases with the linear distance between the upper and lower ends of the surface drained, and with the gentleness of its fall." When the drainage area is small, and has a comparatively impervious surface, the time necessary to establish equilibrium between precipitation and discharge—or to form what is termed "the drainage vehicle" in the foregoing—is relatively short; and as the distance that the rainfall has to travel over the surface before reaching some pipe or channel directly connected with the sewers is generally quite short in populous districts, it will be seen that the maximum rates of rainfall corresponding to such short times must be considered in estimating the volume of storm-water instead of average rates deduced from relatively long periods of time; also that the time will diminish in same proportion as the amount of impervious surface on the area increases. The latter, however, may be regarded in the case of cities as directly proportional to the density of the population up to a certain limit, after which it remains substantially constant, and hence the necessity of ascertaining the probable relation between these two elements before undertaking to compute dimensions for sewers in cities which are not yet fully developed.

Several attempts have been made to express the general principles above set forth in mathematical terms, but without much success from a scientific standpoint. The eminent English engineer, Hawksley, endeav-

ored to find a relation between the diameter of a circular conduit or sewer, the magnitude of the drainage area, the general slope of the surface, which was assumed to be parallel to the inclination of the sewer, and a rainfall of one inch per hour, on the assumption that half of the water would be discharged by the sewer within one hour. After many trials he finally invented the famous empirical formula which bears his name, and from which a few others have since been deduced. Foremost among these derivatives stands the expression proposed in 1880 by the distinguished Swiss engineer, Bürkli-Ziegler, but as it is merely Hawksley's formula in a somewhat different form, although admitting of a wider range of application by means of variable co-efficients, it cannot be characterized as a great improvement over the original. With reference to Hawksley's formula, Colonel J. W. Adams, Hon. M. Am. Soc. C. E., in his excellent work on Sewerage, remarks that: "While it gives ample capacity for the smaller dimensions of sewers and for limited areas, it did not prove so satisfactory in the larger," and he accordingly proposes a different empirical expression which, while "giving slightly less results in the smaller areas, give the increased dimensions in the larger that experience has pointed out as desirable in this locality." The latest of such formulas is the one proposed by R. E. McMath, M. Am. Soc. C. E., of St. Louis, in the Transactions of the American Society of Civil Engineers for 1887; it is modeled after that of Bürkli-Ziegler, but with a different empirical exponent, so that materially different results are obtained.

As it may be of interest to compare these four different formulas with each other, as well as with reliable observations, they have for convenience all been reduced to the same notation by the writer; and to make the first and third named applicable to other rates of rainfall than one inch per hour, this factor has been introduced in making the necessary transformation. Accordingly, with the following notation: (Q) = maximum discharge of the outlet sewer in cubic feet per second; (r) = maximum rate of rainfall in inches per hour, which is practically the same as if expressed in cubic feet per acre per second; (A) = magnitude of the drainage area in acres, and (s) = the sine of the general slope of the surface, or the quotient of the average fall divided by the average length, we will have the formulas given on the next page.

It may be remarked that the first and third expressions relate to ordinary urban conditions of surface, and are designed to apply best when

(1.) Hawksley.............. $Q = 3.946\ Ar \sqrt[4]{\dfrac{s}{Ar}}$

(2.) Bürkli-Ziegler.. $Q = \left(\dfrac{1.757 \text{ to } 4.218}{\text{Average } 3.515}\right) Ar \sqrt[4]{\dfrac{s}{A}}.$

(3.) Adams..... .... $Q = 1.035\ Ar \sqrt[12]{\dfrac{s}{A^2 r^3}}.$

(4.) McMath....... $Q = \left(\dfrac{1.234 \text{ to } 2.986}{\text{Average } 2.488}\right) Ar \sqrt[5]{\dfrac{s}{A}}.$

$r = 1.0$; while in the second and fourth expressions the smaller co-efficients refer to suburban, and the larger to densely populated districts, the average referring to the same conditions assumed in the first and third. It will also be observed that in formulas 1 and 3, the ratio $\left(\dfrac{Q}{Ar}\right)$ will diminish as the intensity of the rainfall increases; but since the fundamental principles of hydraulics teach that the resistances to flow diminish rapidly with an increase of depth or volume, the writer is constrained to believe that there is a defect in these expressions which will manifest itself particularly in the case of relatively small drainage areas. For large districts, on the other hand, it may be conceded that the said ratios may perhaps not increase perceptibly within the range of usual intensities; nevertheless there is certainly no reason apparent why they should diminish when the rate of rainfall increases. The only justification for such a diminution lies in the circumstance that very heavy intensities usually last only a short time, and that consequently the whole area may not be contributing to the observed maximum discharge; but as this depends entirely upon the form, magnitude and slope of the territory, it is obvious that the said formulas must be used with great caution.

The safer method, in the writer's opinion, will be to estimate the probable future amount of impervious surface on the given area, either with reference to the density of population or in any other more reliable manner that may be devised, and to assume that all of the water which falls upon such surface will run off without loss; further, since the topography of the area is supposed to be known, the grades and length of the longest tributaries to the outlet sewer can readily be determined, as well as their approximate diameters, and thence also the velocities of flow therein; from these elements, the time required for the flood-waters to reach the outlet sewer from the most

distant points in the area can next be found, and when the relation between the probable maximum intensity of the rain and its corresponding duration are known, as exhibited in the preceding, the maximum rate of rainfall belonging to the time so found can then be deduced. By proceeding in this manner, it is believed that the least error will accrue in the results, and that the dimensions of a sewer so computed will be found adequate until the assumed amount of impervious surface or density of population has been exceeded.

It may be urged that the process indicated is nothing more than a crude approximation, and that some one of the various empirical formulas might as well have been applied; but to this it may be answered that the method is at all events intelligible and rational, besides being founded upon a somewhat better array of ascertained facts than is the case with the empirical formulas mentioned; it also has the merit of compelling the exercise of an engineer's judgment and discretion with respect to the future of particular localities of a city, or even of different portions of the same large drainage area, instead of dealing alike with all. Moreover, it rarely happens that the history and composition of such formulas become known to the majority of those who may be called upon to apply them, and hence a process in which every single component can be thoroughly scrutinized and amended to suit different circumstances will generally prove to be safer than the application of indefinite rules.

In the foregoing an attempt has been made to exhibit briefly the methods by which engineers of the widest repute and experience have been accustomed to estimate the greatest amount of rainfall, or storm-water, for which provision should be made in the sewers of populous districts, and a modification of these processes was suggested by the writer, inasmuch as the data underlying such methods appear to be entirely inadequate to warrant unqualified acceptance. A careful analysis of all available records of the actual discharge of sewers in times of heavy or protracted rain, undertaken some years ago, revealed enormous incongruities or anomalies which could only be explained by erroneous premises, and which accordingly left the whole subject in a very unsettled condition from a scientific standpoint; hence, when circumstances recently enabled the writer to carry out a series of gaugings of the flood-discharge of a number of large sewers in the city of Rochester, N. Y., he made every possible effort to discover a more trustworthy

relation between the rainfall and the corresponding maximum flow from the surface of a variety of urban districts. An account of these operations, together with the principal results of the computations involved, is herewith submitted.

It may be remarked in the outset that while many of the difficulties subsequently encountered were duly anticipated, yet the writer did not appreciate fully the extreme delicacy with which the sewer-discharge always responds to variations in the intensity of the rainfall until a large number of observations had been collected and the tedious computations completed; neither had he any reason to believe from existing records that rainfalls of uniform intensity for considerable periods of time were so comparatively rare. As a consequence, it was learned too late that the most delicate and accurate self-registering rain gauges were essential to the complete success of the experiments, and that a comparatively large number of such devices should be distributed over the urban drainage area in order to detect all local variations in the rate of precipitation. The results obtained from the gauges used in the work are therefore susceptible of much criticism, yet it must be remembered that not only were no precedents for the undertaking available, but also that the appliances and methods of observation adopted were, on the whole, much more trustworthy than in the case of similar published experiments elsewhere.

The general plan of the work was as follows:

First.—The rainfall was observed at four different stations within the city limits, located from three-fourths to one and one-half miles apart, as already described. The observers were all urged to take the utmost care in noting the exact duration of each heavy rain, and also to record the duration and weight or depth of the water caught when the intensity of the rain appeared to vary, thus dividing an irregular storm into its component parts or showers. Independent records of relative intensity and duration of such rains were also kept by the writer and his immediate assistants, who by constant practice and comparison with the measured results were soon enabled to form a tolerably accurate estimate of the rate of precipitation from both the sound of the rain upon the roof of the building and the appearance of the street gutters. The two gauges maintained by the writer were placed about 35 feet above the surface of the ground at the Municipal Gas Works and the Rochester Bridge Works, where they were entirely free from the influence of sur-

rounding buildings, while the Signal Service gauge was located over 100 feet above the surface on the top of the tower of a lofty building in the center of the city, and the Water Works gauge was stationed on the bank of Mt. Hope Reservoir, which is on the crest of the range of hills in the southern districts. A comparison of the records of these four gauges afforded the means of determining whether the rainfall was evenly distributed over the whole territory.

Second.—The maximum flood-flow in the principal outlet sewers of the east side was obtained by means of self-recording gauges located both in the manholes and in the open channels or ditches which receive the discharge of such sewers in the suburbs. Owing to the nature of the liquid, delicate mechanical appliances could not be used for securing such measurements, as the solid matters in suspension would quickly obstruct the satisfactory operation of such instruments; and after much experimenting, the following simple device was found to give the best results. A thin strip of wood 4½ inches wide and ½ inch thick was painted white and coated with a thin wash of whitening or pulverized chalk, and immediately sprinkled over with carefully sifted coarse sand; thus prepared, it was then inserted and fixed in a suitably grooved and narrow frame, which was securely fastened to the side walls of the manhole, or in an enclosed and locked framework secured to a post driven into the bottom of the ditch. The strip rested at its lower end upon an iron support firmly screwed to the frame, and its rise by flotation was prevented by fitting it snugly under the curbing or covering of the manhole, and by a locking device in the case of the open channels. Being exposed on both sides to the water or sewage, the thin wash of whitening was quickly softened by contact with the liquid, and the sand immediately dropped away from all places which had become immersed, but remained fixed on the surface of the strip above the flow-line. A sharply defined maximum flood-mark was thus obtained in almost every instance, and from the height of this mark, as well as from the previously ascertained relation of the iron support to the bottom of the sewer or channel, the greatest depth of the stream was definitely known. The cross-sectional dimensions and slopes of the several sewers and channels so gauged were also carefully measured, so that all of the elements required for the computation of the maximum discharge were available. These gauges were examined immediately after every hard rainfall or shower, and the surfaces of the strips newly prepared as above

described. It had been noticed previously by the writer that the discharge of certain large sewers in this city varied with the intensity of the rainfall, as well as with its duration, and numerous subsequent observations during the past year abundantly corroborated the view that comparatively slight variations in the rate of precipitation are quickly felt in the sewers, thus establishing the fact that the flood-marks must be attributed to the maximum intensities of the rain during relatively short periods of time, and not to the average intensity for the entire duration of the storm unless it be proven that the same was uniform throughout. The greatest care is therefore necessary in the observation of the rainfall and its variations, otherwise the deductions from the sewer-gaugings become highly deceptive. It may also be mentioned that the period of maximum discharge is usually equal to the duration of the corresponding maximum intensity of the rain, and that the flow is not in the form of a short, sharp-crested wave of momentary duration like that produced from a flushing tank. Thus, in a heavy shower lasting twenty minutes at uniform intensity, the maximum sewer discharge will continue for about the same length of time; and as this period is amply sufficient to flood any cellar or basement when a sewer is overcharged, the damage is then as great as if the duration had been longer. The importance of dealing with shorter periods of time than heretofore customary will accordingly be apparent.

Third.—To obtain the hydraulic slope in case of great depths of flow, or when the sewers are overcharged, the gauges were arranged in pairs, one being placed in each of two consecutive manholes in the same sewer; in the open channels they were likewise arranged in pairs, from 90 to 300 feet apart. In nearly every instance the manholes were located at the junctions of tributary sewers, and the gauges were placed in such manner as to be least affected by the inflow of water from such lateral pipes or conduits. It was also noticed that where the bottom of the main sewer was on a continuous grade, the depth of flow at the lower manhole or junction was always somewhat greater than at the upper one, a circumstance necessarily due to the inflow of the contributions from the intervening territory and the lower lateral sewers. Unfortunately, there were generally no intermediate manholes between such junctions, and hence the true hydraulic slope could not be definitely ascertained. It was, therefore, assumed that when the difference in depth of flow at each pair of manholes was not great, the surface slope would be par-

allel to the bottom slope, as determined by careful leveling, and that the back-water curve or "remous" caused by accretions at the lower manhole would practically not extend up to the upper manhole, since the distance between the two always amounted to several hundred feet. On the other hand, when the sewers were overcharged, the true hydraulic slope was given directly by the gauge records, except in cases where the engorgements were so great as to cause the storm-water to rise above the tops of both manholes and to flood the adjacent low grounds; in such event no definite estimate of the flood-discharge is possible, and the nearest approximation is the maximum capacity of the sewer under various conditions of flow. Again, when the difference in depth of flow was so great as to warrant the inference that the back-water curve extended beyond the upper manhole, the hydraulic slope for computing the discharge at said manhole was estimated as being somewhat less than the bottom slope, and somewhat greater than the slope given by the gauge readings, in order to compensate for the inflow at the lower manhole.

Fourth.—The tributary drainage area behind each gauge was carefully computed from a topographical map of the eastern half of the city, upon which all existing sewers had been indicated, together with their direction of flow and relative size. The division lines between the various separate areas are necessarily approximations, as it would be impracticable to define exactly the actual limits in the great majority of cases, owing to the fact that few of the dividing ridges are distinctly marked or noticeable, and that in many instances the natural course of the drainage has been reversed in order to obtain an outfall into existing sewers. Much time and study were devoted to this matter, and it is believed that the errors so made are insignificant. Having thus learned the form and magnitude of each main area tributary to the sewers at the said gauges, computations of the time required for the storm-waters from the most distant points on the surface to reach each gauge by flowing through the tributary and main sewers were next made, and for this purpose it became necessary to make use of the records of the grades and dimensions of such sewers filed in the office of the City Surveyor. In a few cases the time actually required for the flood to make its appearance, or rather to attain its maximum height, at the gauge, was also observed and compared with the computed time, the result being that the former always exceeded the latter by several minutes, thus indicating that the water requires a certain length of time to reach

the sewers from the roofs, and more especially from the street surfaces. With the information thus obtained, the increased discharge at the lower gauges could readily be compared with the volume that would probably be delivered by the tributaries which entered the sewer at that point, and where the discrepancy between these two quantities was found to be large, the observations were rejected.

Fifth.—Thirty-one of the above described automatic flood gauges were located in eleven different main sewers and five open ditches or channels within the city limits, whereby an opportunity was afforded to observe the maximum discharge from twenty-four drainage areas, varying in magnitude from 25 acres to 606 acres, and presenting a great diversity of character with reference to quality of soil, density of population, class of roadways and extent of sewerage. Few of these districts, however, were similar in general character, and hence the final results cannot well be compared. For the sake of brevity the essential data relating to said districts have been arranged in Tables Nos. 1 and 2, hereto appended. It should be stated that in many cases the observations of the flood-flow were useless, as no reliable record of the rainfall was at hand; also that of the remaining observations only those which related to rainfall intensities of about 0.25 inch and upward per hour have thus far been worked out in detail for some of the most populous and best sewered districts. To a number of these computations, moreover, considerable uncertainty is attached, by reason of the irregularities in grade of the sewers; and hence in the following the results from only a few of the entire number of districts above mentioned can be submitted with confidence.

Sixth.—The discharge was computed with variable co-efficients deduced from Kutter's formula, and in a few instances where experiments were made, the computed velocities were found to agree closely with the observed average velocities between the gauges. Weir measurements would doubtless have been far more satisfactory; but as a matter of fact, none of the sewers were large enough to admit of using this method of gauging during heavy showers. In the distant suburbs it was possible to find a few places in the natural water-courses where a weir could have been applied without damaging the adjacent low lands by overflow or back-water; yet as the particular object of the gaugings was to obtain the maximum proportion of rainfall which finds its way into the sewers of the urban districts, the purpose would have been utterly defeated if large

tracts of agricultural land had been thus included in the tributary areas. No other process of gauging than by computing the discharge from some approved formula for the flow in a regular channel was therefore practicable.

Seventh.—The percentage of the rainfall which is discharged by the sewers during the period of maximum flow depends, as previously stated, chiefly upon the greatest intensity of the precipitation during the continuance of the storm ; and if the average intensity were used in computing such percentages, an assortment of results would be obtained which are manifestly absurd from their enormous magnitude. For example, let us consider the case of the rain on June 2d, 1888, when a heavy shower lasting fifteen minutes was followed by thirty-five minutes of light rain of probably less than one-fourth of the previous intensity, and by a light drizzle lasting fifteen minutes more, after which the rain ended. The rain had thus a continuous duration of sixty-five minutes, and yielded a total depth of 0.152 inches in all parts of the city, its average intensity being 0.14 inches per hour. On this day, however, the Court and William Streets outlet sewer showed at the intersection of Alexander Street and University Avenue a maximum flow of 19.97 cubic feet per second from a drainage area of 132.96 acres ; but at the said average intensity, the amount of water falling upon the entire area is only 18.6 cubic feet per second, and hence on this assumption the sewer would have discharged over 100 per cent. of the average rainfall, which is a palpable absurdity. On the other hand, it was estimated that during the fifteen minutes of the heavy shower at least two-thirds of the whole amount of water fell, which would give a maximum intensity of about 0.40 inch per hour, and hence also a precipitation of 53.2 cubic feet per second upon the whole drainage area ; thereby reducing the percentage of the rainfall discharged by the outlet sewer to 37.5, which is doubtless not far from the truth, since about 38 per cent. of the surface may fairly be regarded as impervious. From the data collected by the writer, many other similar instances might be adduced, but it is believed that the foregoing one will suffice as an illustration of the necessity of the most minute and careful observation of the rainfall.

During the past year seventeen noteworthy rainfalls, ranging in maximum intensity from 0.24 inch to 3.20 inches per hour, have been more or less accurately observed in this city at the several stations mentioned, and for nearly all of these the corresponding maximum flow in the

sewers was obtained in the manner described. The complete analysis and description of these rains, as deduced from the various records by the writer, are given in full detail in Table No. 3; and a summary thereof exhibiting only the maximum intensities and durations of the component showers, along with some explanatory remarks, is given in Table No. 4, hereto appended. It should be mentioned that no great accuracy for the figures thus exhibited is claimed, as the rates of the component showers are generally estimates based upon numerous actual measurements; the total precipitation and the timings, however, can be accepted with much confidence in the majority of cases, as the errors are relatively small. The light rains and drizzles are always small fractional parts of the total fall in the class of storms here considered, and a close knowledge of their intensities can soon be acquired by practice; hence, when the duration of these estimated lighter rains is known, together with the total fall, the intensities of the heavy component showers can be reached with a fair degree of certainty. In this manner the rates for the heavy rains were estimated, as shown in Table No. 3; and in the absence of data from the most delicate self-registering rain gauges, they are submitted as the best which the writer can offer. No revision of them has been attempted in order to secure more harmonious correspondence with the sewer gaugings, and they are accordingly open to amendment, along with the computed percentages of discharge.

The storm-discharge from five different districts in this city may now be considered, the general description of these districts being as follows:

District I.—Discharge measured at gauge No. 2 in the Clifford Street and Avenue B outlet sewer at the intersection of Avenue B and Harris Avenue. About one-half of the total irregular tributary drainage area of 356.94 acres has a dense population, averaging about 35 per acre, while the remainder is thinly settled and presents much agricultural land. The soil is generally a clayey loam, with gravel and muck in some places; its surface is slightly undulating, with no sharply defined natural water-courses. Nearly all of the existing streets are sewered and have graded earthen roadways and gutters, and only a very small proportion of the aggregate length of roadway is macadamized. The average grade of the sewered streets is about 1 in 150, and the sewer grades range from 1 in 47 to 1 in 910. Few large buildings or factories are found in the district. The outlet sewer appears to be in excellent order, and affords good facility for gauging at all depths of flow.

District IV.—Discharge measured at gauge No. 8, in the North Avenue outlet sewer, near Syracuse Street. The tributary drainage area of 128.67 acres is generally well developed, and is in the form of an irregu-

lar strip 4 800 feet long by about 1 200 feet average width, beginning in the central part of the city and extending northerly. The average density of population may be estimated at about 32 per acre. The area contains many large business blocks and other buildings along North Avenue, but the rest of the territory is occupied chiefly by residences of medium size standing on moderately large lots. The soil is mainly a clayey loam, with muck in the lower districts, and the surface slopes gently to the north as far as the New York Central and Hudson River Railroad, after which it becomes very flat. All of the streets are sewered and graded, and about one-third of the aggregate length of roadway has been paved with asphalt, stone blocks, macadam and gravel, the macadam, however, predominating in extent; the remainder of the roadways are of common earth. The average grade of the streets is 1 in 130, and the sewer grades range from 1 in 50 to 1 in 630. The outlet sewer is of good rubble masonry, with a flat bottom, excavated in a horizontally stratified limestone rock; for small depths of flow no great accuracy can be expected from the gaugings.

District X.—Discharge measured at gauge No. 18, in the East Main Street sewer at the intersection of North Union Street. The tributary drainage area of 25.12 acres is well developed, and is in the form of a long and comparatively narrow strip traversed by East Main Street, along which many large business blocks and apartment houses have been built. There are, however, still many detached small residences on the area, with considerable garden space. The average density of population may be estimated at about forty per acre. The soil is a clayey loam, and its surface inclines moderately to the east. Almost every street is sewered and provided with a macadamized or gravel roadway, the average surface grade being 1 in 172, while the sewer grades vary from 1 in 70 to 1 in 330. The outlet sewer is of ordinary rubble masonry, with a flat bottom of rock, hard-pan or plank. For small depths of flow the gaugings are probably unreliable. From this district the greatest percentage of discharge may be expected, as it contains the largest proportion of impervious surface of any in the whole list.

District IX.—Discharge measured by gauge No. 19, in the Court and William Streets outlet sewer at the intersection of Alexander Street and University Avenue. The tributary drainage area of 132.96 acres is chiefly a well developed residential district, with a few large buildings and apartment houses. Most of the dwellings are large and stand rather close together on lots of medium size. The average density of population is about thirty-six per acre. Every street is sewered and graded, and the roadways are nearly all improved with macadam or gravel, but there is not a single first-class pavement in the whole district. The soil is generally of a loamy character, with some clay, gravel and muck in different portions; its surface is somewhat undulating, the prevailing slope, however, being towards the north and east; the average grade of the streets

is about 1 in 151, and the sewer grades range from 1 in 54 to 1 in 400. The outlet sewer is of ordinary rubble masonry, with a flat bottom excavated in the limestone rock and trimmed to the slope; hence it is not well adapted to the gauging except when running at considerable depths. From the general character of this district, a relatively large percentage of discharge may be expected.

District XVII.—Discharge measured by gauge No. 30 in the Griffith Street sewer at the intersection of Broadway. The tributary drainage area of 92.27 acres is well sewered and developed, and the average density of population may be taken at about 35 per acre. Almost every street has been improved, about one-fifth of the aggregate length being paved with asphalt, one-fourth with stone blocks, and the remainder with macadam and gravel. The territory contains a number of large business blocks and apartment houses, but the greater portion is occupied by detached residences standing on lots of medium width. In one district of about twenty-five acres the lots are very deep and afford opportunity for additional streets. The soil is mainly a clayey loam; its surface slopes generally to the south, but in the aggregate one-half of the whole area is quite flat. The average grade of the streets is 1 in 240, and the sewer grades vary from 1 in 100 to 1 in 350. The sewerage is not of the best description, and the outlet has frequently been overcharged. It is reasonable to infer that the proportion of rainfall reaching the sewers is less than in the preceding district.

The foregoing five districts have been selected from the entire number available because they represent not only the best developed and most populous localities on the east side, but also the largest and most accessible outlet sewers. It is greatly regretted that much doubt with respect to the bottom slope of some of the other sewers, or of the same sewers at other gauges, prevents the utilization of the records obtained until such time as the nominal grades may be tested by numerous excavations; but the computations for several of these other districts show such wide differences and improbabilities as to greatly impair their value ; furthermore, most of these districts include large tracts of agricultural or unimproved territory, and are therefore of minor interest in connection with the discharge from populous areas. The combined flow from a series of contiguous districts was measured a number of times by gauges 9 and 10, 11, 12 (a) and 13, and 12 (b) ; but as it was impracticable to determine each component separately, the gaugings must necessarily relate to large territories, and can serve only to check the computations made for the smaller areas in which the essential elements were known with reasonable certainty. For these reasons only a

part of all the records secured are now of use, while the remainder must be laid aside until the sewer grades can be properly verified hereafter.

Some of the details of the discharge computations for the aforesaid five districts are given in the appended tables, Nos. 5, 6, 7, 8 and 9, while Table No. 10 shows the computed percentages of the heaviest rainfall so discharged during the period of maximum flow. To exhibit these important results in more convenient and compact form, however, they are herewith submitted in the table on the following page.

It will be noticed that there are numerous discordances in this table, most of which can fairly be ascribed to imperfect estimates of the maximum intensity of the rainfall, while the remainder have doubtless arisen from errors made in observing the flood-marks left on the sewer gauges. Fortunately, however, the data are sufficiently numerous to admit of comparison; and by averaging the results obtained for similar durations of heavy rain it is probable that the majority of the discrepancies will be equalized, and that the mean values of the percentages of the rainfall so removed by the sewers will afford a clue to the general laws which govern such discharge. For facilitating the study of the problem, these average values for each of the districts were plotted as ordinates with the corresponding durations of the maximum rainfall as abscissas, thus obtaining a series of five somewhat irregular curves shown in Plate No. II.; and upon carefully examining these diagrams in conjunction with the explanatory remarks relating to both the rainfall and the sewer gaugings, the irregularities were corrected or equated by suitably fitting regular lines or curves to the various points obtained as stated. These new lines or curves accordingly represent a more or less close approximation to the actual relation of the rainfall to the flood flow in the sewers of populous districts; and while the numerical results thus reached may not be absolutely correct, the diagrams nevertheless point unmistakably to the following general conclusions:

First.—The percentage of the rainfall discharged from any given drainage area is nearly constant for rains of all considerable intensities and lasting equal periods of time. This circumstance can be attributed only to the fact that the amount of impervious surface on a definite drainage area was also practically constant during the time occupied by the experiments.

TABLE E.

SHOWING the computed percentages of the heaviest rainfall discharged from five different city districts by the respective outlet sewers during the period of maximum flow, also the average values of such percentages. Arranged with reference to duration of heaviest rainfall.

DATE.	Maximum intensity of rainfall, inches per hour.	Duration of rain at maximum intensity, minutes.	Percentages of rainfall discharged.				
			Dist. I.—Gauge 2; trib. area, 356.94 acres.	Dist. IV.—Gauge 8; trib. area, 128.67 acres.	Dist. X.—Gauge 18; trib. area, 25.12 acres.	Dist. IX.—Gauge 19; trib. area, 132.96 acres.	Dist. XVII.—Gauge 30; trib. area, 92.27 acres.
December 10th, 1887....	0.31*	60	13.8	24.1	58.2	41.6	26.0
September 16th, 1888....	0.47‡	50	19.8	38.2	—	—	37.2
Averages..............	....	55	16.8	31.1	58.2	41.6	31.6
May 9th, 1888............	1.315‡ to 0.75†	35	16.4	26.2	52.1	29.0	26.0
April 5th, 1888...........	0.24*	30	10.4	15.5	—	38.2	20.8
May 12th, 1888...........	0.30*	30	11.0	15.8	35.3	29.6	17.0
Averages..............	....	30	10.7	15.7	35.3	34.9	18.9
June 24th, 1888..........	2.62‡	20	6.3	21.1	32.0§	13.2§	11.8§
June 28th, 1888..........	0.80*	20	14.3	28.7	35.2	35.2	37.4
Averages..............	....	20	10.3	24.9	33.6	24.2	24.6
June 2d, 1888	0.40‡	15	5.5	9.0	—	37.5	8.7¶
July 11th, 1888	0.76††	15	7.4	15.8	41.2	21.8	19.4
August 16th, 1888........	1.616†	15	4.7	12.5	24.7	18.0	19.1§
Averages..............	....	15	5.9	12.4	32.9	25.8	19.2
May 4th, 1888	0.30*	13	6.8	14.4	64.8¶	36.1¶	28.2¶
May 26th, 1888..........	1.00*	13	8 6	25.9¶	31.8	18.7	11.7
August 4th, 1888.........	1.00‡	12	4.6	10.0	—	15.0	13.8
August 26th, 1888........	2.50†	14	4.0	12.2	33.5§	13.8§	12.3§
Averages	....	13	6.0	12.2	32.6	15.8	12.6
July 18th, 1888..........	0.75*	10	7.6	12.2	25.0	14.8	10.3
August 17th, 1888........	1.33‡	10	5.5	8.7	18.4	11.9	8.9
Averages	....	10	6.5	10.4	21.7	13.3	9.6
Probable time required for concentration of flow at gauges, minutes..............	....	....	44	26	16	23	24

* Preceded and followed by lighter rain.
‡ Sudden shower, followed by lighter rain.
†† Heavy shower, preceded by lighter rain.
† Intensity roughly estimated.
§ Sewer here ran under head; percentage is computed from maximum discharge without head previous to surcharge.
¶ Figures obviously too high or low and rejected in deriving averages.

Second.—The said percentage varies directly with the degree of urban development of the district; or, in other words, with the amount of impervious surface thereon. This fact is clearly shown by the large percentages derived from the relatively best developed District X, in contrast with the smaller percentages obtained from the relatively less improved Districts IX, IV and XVII, and to the still smaller results yielded by the least improved District I; and it also serves to account for the constancy of the percentage discharged from any particular district for rainfalls of the same duration.

Third.—The said percentage increases rapidly, and directly or uniformly, with the duration of the maximum intensity of the rainfall, until a period is reached which is equal to the time required for the concentration of the drainage waters from the entire tributary area at the point of observation; but if the rainfall continues at the same intensity for a longer period, the said percentage will continue to increase for the additional interval of time at a much smaller rate than previously. This circumstance is manifestly attributable to the fact that the permeable surface is gradually becoming saturated and is beginning to shed some of the water falling upon it; or, in other words, the proportion of impervious surface slowly increases with the duration of the rainfall.

Fourth.—The said percentage becomes larger when a moderate rain has immediately preceded a heavy shower, thereby partially saturating the permeable territory and correspondingly increasing the extent of impervious surface.

Fifth.—The sewer-discharge varies promptly with all appreciable fluctuations in the intensity of the rainfall, and thus constitutes an exceedingly sensitive index of the rain and its variations of intensity.

Sixth.—The diagrams also show that the time when the rate of increase in the said percentages of discharge changes abruptly from a high to a low fig[illegible] agrees closely with the computed lengths of time required for the concentration of the storm-waters from the whole tributary area; and hence the said percentages at such times may be taken as the proportion of impervious surface upon the respective areas. For example, the percentage curves for District IV and XVII are seen to be practically coincident, whence it might be inferred that the proportions of impervious surface are alike in both areas; as a fact, this conclusion is fully warranted by an examination of the two territories, which are separated by a large intermediate area.

The relation between the maximum sewer-discharge and the rainfall has thus been approximately established for five different districts in this city, and it has been seen that the flood-volume stands in direct proportion to the magnitude of the impervious surface on the drainage area, and to the intensity and duration of the rain; also that such flood-volume reaches practically a maximum when the precipitation continues uniformly for a sufficient length of time to secure the concentration of the storm-waters from all portions of the area. The element of time, therefore, enters twice into the determination of the flood-volume, and from the relation between duration and maximum intensity of the rainfall in this locality heretofore established, we may accordingly find the duration of that particular rainfall for which the sewer-discharge will become an absolute maximum. With the following notation: (r) = maximum intensity of the rainfall in inches per hour; (t) = duration in minutes of such intensity; (Q) = sewer discharge in cubic feet per second; (A) = magnitude of the entire drainage area in acres; (m) = proportion of impervious surface on said area, which is also substantially the same as the proportion of the rainfall discharged during the period of greatest flow; and with $(a, b$ and $c)$ = certain empirical constants, we will have—

(1st).................................... $Q = m A r;$
(2d).................................... $m = a t;$
(3d).................................... $r = b - c t;$
(4th).................................... $Q = A a t (b - c t);$

and for the usual condition under which (Q) will become a maximum, we obtain:

(5th)...................... $A a (b - 2 c t) = O$, whence:.. $t = \frac{b}{2c}$.

But in the foregoing it was shown that the values of the empirical constants (b) and (c) were, for rainfalls lasting less than one hour in the locality of Rochester, $b = 2.10$ and $c = 0.0205$; hence the duration (t) of the heaviest rain which will cause (Q) to become an absolute maximum is: $t = 51$ minutes. This solution, however, is to be regarded simply as a crude approximation and valid only under certain circumstances; but it suffices to show that in drainage areas of moderate size, the heaviest discharge always occurs when the rain lasts long enough at its maximum intensity to enable all portions of the area to contribute to the flow. For large areas, on the other hand, a more elaborate analysis becomes necessary in order to find under what conditions the absolute

maximum discharge will occur, although the method of procedure above indicated will remain the same.

The present percentages of the rainfall discharged from the aforesaid urban districts cannot, however, be regarded as permanent, since improvements are constantly being made by the construction of new buildings, pavements and sewers; hence not only is the proportion of impervious surface on these districts steadily growing, but the time required for the concentration of the storm-water in the outlet-sewers is also becoming materially reduced. In planning new sewers, therefore, it will be necessary to provide for the drainage from districts which, sooner or later, will be much better developed than any of those described above; and in the absence of more trustworthy data, we may be justified in concluding that the greatest percentages of discharge from such improved districts will continue to be practically equal to the percentages of impervious surface thereon, as was found to be the case with the five districts described.

The results of the flood gaugings are thus seen to be in general accord with the above described process, suggested by the writer for computing the necessary capacity of sewers on the "combined" system, and hence the method may be considered as reasonably accurate. To indicate what figures the writer adopted in computing the maximum flow in the several sections of the proposed east side trunk sewer, it may be stated that four different classes of territory were taken into account, as follows: Class I, with 50 persons per acre and 55 per cent. of impervious surface; Class II, with 40 persons per acre and 46 per cent. of impervious surface; Class III, with 25 persons per acre and 27 per cent. of impervious surface, and Class IV, with 15 persons per acre and 14 per cent. of impervious surface. It should also be stated that the central districts of the city, which will in the future undoubtedly afford a considerably higher percentage of impervious surface than has been assigned to Class I, are not embraced in the drainage area of said trunk sewer; furthermore, that in the estimate of these percentages a much better condition of the roadways and pavements has been assumed than now prevails.

In conclusion, it may be of interest to make an application of the above method and compare the result with the results given by the four formulas mentioned. For this purpose, let us consider District I, already described, with an area of 360 acres, which may, in the future,

be constituted as follows: 60 acres of Class I, 90 acres of Class II, 120 acres of Class III, and 90 acres of Class IV, thus giving 119.4 acres, or 33 per cent., of impervious surface, and a population of 10 950, or an average density of about thirty persons per acre; these conditions will doubtless be recognized as representing medium urban territory, to which any of the four formulas are directly applicable; furthermore, let it be assumed that the time required for the concentration of the storm-waters at the lower end of this district is: $t = 44$ minutes, and that the average surface slope of the streets is $s = \frac{1}{150}$, with sewer grades ranging from 1 in 50 to 1 in 900, the main collector, however, having an average grade of 1 in 500. For the probable maximum intensity of the rainfall continuously during forty-four minutes we will have from Equation 3: $r = 2.10 - 0.0205\,t = 1.20$ inches per hour (or cubic feet per acre per second), and hence the volume of storm-water running off into the sewers from the 119.4 acres of impervious surface will at first be $= 119.4 \times 1.2 = 143.3$ cubic feet per second; but as the rain lasts uniformly for so long a time, it may be considered that the permeable area has become partially saturated, and will toward the close of the rain be contributing about 15 per cent. of the precipitation thereon to the sewers, thus giving an additional quantity of $240 \times 1.2 \times 0.15 = 43.2$ cubic feet per second, or a total storm-flow of 186.5 cubic feet per second. With a water-supply of 100 gallons per head per day, and one-half of this amount flowing off as sewage uniformly in six hours, the volume of sewage will be about 3.5 cubic feet per second; and hence the required capacity of the sewer at the lower end of said district should be, according to the writer's method: Q = 190 cubic feet per second.

On the other hand, we will obtain from Hawksley's formula, which predicates that $r = 1.0$, and that (s) is the sine of the slope of the outlet-sewer, or in this case $s = \frac{1}{500}$:

(1) $Q = 3.946\ A \sqrt[4]{\frac{s}{A}} = 68.97$ cubic feet per second; or, if the formula be taken as above transcribed, with $r = 1.2$ and (s) denoting the sine of the average surface slope, or $s = \frac{1}{150}$:

(1*) $Q = 3.946\ Ar \sqrt[4]{\frac{s}{Ar}} = 106.66$ cubic feet per second.

From Bürkli-Ziegler's transcribed formula, with the average value of the co-efficient $= 3.515$, $r = 1.2$ and $s = \frac{1}{150}$, we find:

(2) $Q = 3.515\ Ar \sqrt[4]{\frac{s}{A}} = 99.44$ cubic feet per second.

The difficulty here is to determine what value shall be given to (r), since Bürkli-Ziegler distinctly states that it should be the maximum which obtains during the continuance of the storm, and assigns to it for central Europe values ranging from 1.75 to 2.75. If an irregular rain lasting forty-four minutes be assumed, it is easy to see that a maximum intensity of 2.40 inches per hour might prevail for a few minutes, with lesser rates for the remainder of the time, and giving an average of 1.2 inches, as above computed; and with $r = 2.40$ we would have double the discharge just computed, or practically the same as the volume calculated by the writer's method.

From Colonel Adams' formula, as transcribed, and which originally predicates $r = 1.0$ and (s) as denoting the sine of the slope of the sewer, or in this case, $s = \frac{1}{500}$, we have:

(3) $Q = 1.035\ A \sqrt[12]{\frac{s}{A^2}} = 83.23$ cubic feet per second; whereas, if we use the values $r = 1.2$ and $s = \frac{1}{150}$, as before, we will obtain:

(3*) $Q = 1.035\ Ar \sqrt[12]{\frac{s}{A^2 r^2}} = 107.05$ cubic feet per second.

In like manner we will find from the transcribed McMath formula, for the average co-efficient $= 2.488$ and $r = 1.2$, with $s = \frac{1}{150}$:

(4) $Q = 2.488\ Ar \sqrt[5]{\frac{s}{A}} = 121.41$ cubic feet per second; but if (r) were taken at the value adopted for St. Louis, *i. e.*, $r = 2.75$, the discharge would be increased to about 278 cubic feet per second, or nearly fifty per cent. more than the volume computed by the writer's method.

In the choice of the several processes of estimating the required capacity of a combined sewer for a populous district, it must be remembered that with the heavy rains of frequent occurrence in this country, the proportioning of sewers by Hawksley's formula has usually resulted in floodings, and that an extensive experience with the other formulas has not yet been gained. The above investigations, moreover, show that larger quantities of storm-water run off from urban surfaces than is commonly supposed, and hence it is obvious that a more rational method of sewer computation is urgently demanded. Much room for improvement in this direction is still left, and it is sincerely hoped that the efforts of the writer will be amply supplemented by many valuable suggestions and experimental data which other members of the Society may generously contribute.

TABLE No. 1.

SHOWING Tributary Drainage Areas at the Different Flood-Gauges in Outlet Sewers.

Number of District.	DESIGNATION OF SEWER.	Number of Lower Gauge.	Tributary Area.	Number of Upper Gauge.	Tributary Area.	Distance between Gauges.	REMARKS.
			Acres.		Acres.	Feet.	
I.	Avenue B Outlet Sewer	1	382.51	2	356.94	897.5	
II.	Lowell Street Outlet Sewer	3	42.80	4	27.42	332.5	
III.	St. Joseph Street Outlet Sewer	5	108.54	6	102.78	473.1	
IV.	North Avenue Outlet Sewer	7	216.08	8	128.67	775.2	
V.	North Avenue Outlet Sewer Ditch	9	484.31	10	484.31	112.2	
VI.	Goodman Street Outlet Sewer Ditch	11	606.62	....	....	....	
VII (a)	Court and William Streets Outlet Sewer Ditch	13	341.21	12a	341.21	527.5	No. 12a changed to 12b, June 29, 1888.
VII. (b)	Court and William Streets Outlet Sewer	....	....	12b	328.72	....	
VIII.	Court and William Streets Outlet Sewer	16	177.56	17	167.95	561.5	
IX.	Court and William Streets Outlet Sewer	17	139.16	19	132.96	846.0	
X.	East Main Street Tributary Sewer	17	28.78	18	25.12	742.7	
XI. (a)	Upton Park Outlet Sewer Ditch	15a	187.68	14	187.68	91.3	No. 15a changed May 14, 1888.
XI. (b)	Upton Park Outlet Sewer Ditch	15b	187.68	14	187.68	116.0	
XII.	Upton Park Outlet Sewer	21	116.30	20	110.11	176.1	
XIII.	East Avenue Outlet Sewer	23	....	22	211.90	1 425.5	No. 23 was reset on May 14, 1888.
XIV. (a)	Monroe Avenue and Nichols Park Outlet Sewer Ditch	25a	125.98	24a	125.98	101.2	Nos. 24 and 25 changed May 14, 1888.
XIV. (b)	Monroe Avenue and Nichols Park Outlet Sewer	25b	116.49	24b	116.49	77.4	
XV. (a)	Pinnacle Avenue Outlet Sewer	27a	177.17	26	161.44	364.8	No. 27 was changed June 19, 1888.
XV. (b)	Pinnacle Avenue Outlet Sewer	27b	177.17	26	161.44	834.8	
XVI.	Mt. Hope Avenue Outlet Sewer	29	245.77	28	243.02	599.5	
XVII.	Griffith Street Outlet Sewer	31	118.22	30	92.27	657.8	

TABLE No. 2.

SHOWING Characteristics of the Several Sewers at the Flood-Gauges.

Drainage District.	Flood Gauges.	Actual Bottom Slope.	Width of Sewer.	Versed-sine of Invert.	Shape of Roof.	Total Height.	Co-efficient of Roughness.	REMARKS.
			Feet.	Feet.		Feet.		
I.	1 and 2	1 in 341	3.10	0.50	semicircle.	5.50	0.015	Brick invert; remainder is rubble masonry in good condition. Grade appears to be regular.
II.	3 and 4	1/1 241	1.92	0.0	flat.	2.00	0.020	Flat earth or plank bottom; rubble masonry in poor condition. Grade probably irregular.
III.	5 and 6	1/473	3.10	0.0	semicircle.	5.55	0.017	Flat plank bottom; rubble masonry in average condition. Grade is probably somewhat irregular.
IV.	7 and 8	1/624	4.00	0.0	"	6.00	0.017	Flat rocky bottom; rubble masonry in average condition. Grade probably somewhat irregular.
VII. (b)	12 (b)	1/200	3.25	1.0	"	5.05	0.015	Brick invert; rubble masonry in good condition (new). Grade appears to be regular.
VIII.	16 and 17	1/185	2.44	0.0	"	3.68	0.017	Flat rocky bottom; rubble masonry in average condition. Grade is somewhat irregular.
IX.	17 and 19	1/185	2.44	0.0	"	3.68	0.017	Flat rocky bottom; rubble masonry in average condition. Grade is somewhat irregular.
X.	17 and 18	1/78	1.50	0.0	flat.	2.20	0.017	Flat rock or hard earth bottom; rubble masonry in average condition. Grade probably irregular.
XII.	20 and 21	1/92.5	2.00	0.0	"	2.50	0.017	Flat plank bottom; rubble masonry in average condition. Discharge by two pipes. See surface slopes of water.
XIII.	22 and 23	1/348	1.83	....	egg-shaped	2.50	0.015	Cement pipe, cracked in many places. Grade may be somewhat irregular.
XIV. (b)	24 and 25	1/187	2.00	0.0	flat.	2.00	0.017	Flat plank bottom; rubble masonry in average condition. Grade irregular.
XV. (b)	26 and 27	1/145	2.00	0.0	"	3.00	0.017	Flat plank bottom; rubble masonry in average condition. Grade irregular.
XVI.	28 and 29	1/593	2.10	0.0	"	3.00	0.017	Flat rocky bottom; rubble masonry in average condition. Grade irregular.
XVII.	30 and 31	1/208	2.00	0.0	"	3.00	0.017	Flat plank bottom; rubble masonry in average condition. Grade probably irregular.

TABLE No. 3.

SHOWING duration and analysis of intensity of the principal rainfalls at Rochester, N. Y., from October 1st, 1887, to October 1st, 1888.

DATE.	Rain Began.	Rain Ended.	Duration. Hrs. Min.	Depth Fallen. Inches.	Assumed rates of Fall, in Inches, per hour.	Equivalent Depth Fallen. Inches.	REMARKS.
December 10th, 1887......	5.30 A.M.	7.00 A.M.	1—30	0.104	0.069	0.104	Moderate rain.
	7.00	9.00	2—00	0.441	0.035	0.070	Light rain.
	9.00	10.00	1—00		0.310	0.310	Heavy rain.
	10.00	11.00	1—00		0.030	0.030	Light rain.
	11.30	12.00 M.	0—30		0.030	0.015	Light rain.
	1.00 P.M.	2.00 P.M.	1—00		0.015	0.015	Drizzling rain.
			7—00	0.545	....	0.544	
April 5th, 1888............	8.40 A.M.	10.40 A.M.	1—30	0.230	0.073	0.110	Light rain.
	8.40	10.40	0—30		0.240	0.120	Heavy rain.
			2—00	....	....	0.230	
May 4th, 1888............	4.05 P.M.	4.13 P.M.	0—08	0.226	0.160	0.021	Moderate rain.
	4.13	4.26	0—13		0.300	0.065	Heavy rain.
	4.26	4.46	0—20		0.020	0.007	Drizzling rain.
	4.46	5.00	0—14		0.250	0.058	Heavy rain.
	5.00	5.18	0—18		0.020	0.006	Drizzling rain.
	5.18	5.30	0—12		0.250	0.050	Heavy rain.
	5.30	5.47	0—17		0.020	0.006	Drizzling rain.
	5.47	6.05	0—18		0.040	0.012	Light rain.
			2—00	....	....	0.225	

May 9th,* 1888	7.25	8.00	0—35	0.767	1.315	0.767	Heavy shower at Municipal Gas Works.
	7.25	8.00	0—35	0.203	0.348	0.203	Light shower at Rochester Bridge Works
May 12th, 1888	2.40	3.00	0—20		0.210	0.070	Moderate rain.
	3.00	3.30	0—30	0.240†	0.300	0.150	Heavy rain.
	3.30	3.40	0—10		0.100	0.020	Light rain.
			1—00	....	....	0.240	
May 26th, 1888	2.15 P.M.	2.20 P.M.	0—05		0.750	0.063	Heavy rain.
	2.20	2.35	0—15		0.170	0.043	Light rain.
	2.35	2.48	0—13	0.345	1.000	0.217	Very heavy rain.
	2.48	2.53	0—05		0.150	0.013	Light rain.
	2.53	3.05	0—12		0.040	0.008	Drizzling rain.
			0—50	....	....	0.344	
June 2d, 1888	9.10 A.M.	9.25 A.M.	0—15		0.400	0.100	Heavy rain.
	9.25	10.00	0—35	0.152	0.080	0.047	Light rain.
	10.00	10.15	0—15		0.030	0.007	Drizzling rain.
			1—05	....	....	0.154	
June 24th, 1888	1.21 P.M.	1.51 P.M.	0—30		1.600	0.800	Very heavy rain.
	1.51	1.54	0—03	0.875	0.100	0.005	Light rain.
	1.54	1.58	0—04		0.900	0.060	Heavy rain.
	1.58	2.18	0—20		0.040	0.013	Drizzling rain.
			0—57	....	....	0.878	
June 24th, 1888	4.30 P.M.	4.50 P.M.	0—20		2.620	0.873	Very heavy rain.
	4.50	4.53	0—03	0.902	0.100	0.005	Light rain.
	5.35	6.00	0—25		0.060	0.025	Light rain
			0—48	....	....	0.903	
June 28th, 1888	5.30 A.M.	7.00 A.M.	1—30	0.320	0.213	0.320	Moderate rain.

* Not uniform over territory.

† Average value; on west side depth was 0.27 inches, and on east side, 0.21 inches.

TABLE No. 3.—(*Continued.*)

DATE.	Rain Began.	Rain Ended.	Duration. Hrs. Min.	Depth Fallen. Inches.	Assumed Rate of Fall, in Inches, per hour.	Equivalent Depth Fallen. Inches.	REMARKS.
June 28th, 1888............	7.00 A.M.	9.00 A.M.	2—00	1.000	0.100	0.200	Light rain.
	9.00	9.15	0—15		0.760	0.190	Heavy rain.
	9.15	9.25	0—10		0.100	0.017	Light rain.
	9.25	10.00	0—35		0.240	0.140	Moderate rain.
	10.00	10.20	0—20		0.800	0.267	Heavy rain.
	10.20	10.25	0—05		0.100	0.008	Light rain.
	10.35	10.40	0—05		0.240	0.020	Moderate rain.
	10.40	10.50	0—10		0.750	0.125	Heavy rain.
	10.50	11.05	0—15		0.120	0.030	Light rain.
			5—25	1.320	....	1.317	
July 11th, 1888............	4.55 P.M.	5.15 P.M.	0—20	0.342	0.150	0.050	Moderate rain.
	5.25	5.40	0—15		0.760	0.190	Heavy rain.
			0—35	....	....	0.240	
July 18th, 1888............	9.50 A.M.	9.54 A.M.	0—04	0.656*	0.500	0.033	Heavy rain.
	11.00	11.25	0—25		0.100	0.042	Light rain.
	11.25	11.35	0—10		0.750	0.125	Heavier rain.
	11.35	12.20 P.M.	0—45		0.200	0.150	Moderate rain.
	12.35 P.M.	2.25	1—50		0.165	0.303	Moderate rain.
			3—14	....	....	0.653	
August 4th, 1888..........	1.00 A.M.	1.12 A.M.	0—12	0.431	1.000	0.200	Heavy rain.
	1.12	2.15	1—03		0.180	0.189	Moderate rain.
	2.15	2.50	0—35		0.080	0.047	Light rain.
			1—50	....	....	0.436	

August 16th, 1888†	2.45	3.50	1—05	0.444	0.410	0.444	Heavy rain.
	5.30	5.45	0—15	0.404	1.616	0.404	Very heavy rain.
	6.15	6.30	0—15	0.064	0.256	0.064	Moderate rain.
			1—35	0.912	....	0.912	On west side.
August 16th, 1888	During	night	unknown	0.535	....	....	On east side.
August 17th, 1888	4.50 A.M.	5.00 A.M.	0—10	0.222	1.333	0.222	Heavy rain.
	5.00	5.35	0—35	0.175	0.300	0.175	Moderate rain.
	5.35	6.00	0—25	0.162	0.388	0.162	Moderate rain.
	6.00	7.00	1—00	0.121	0.121	0.121	Light rain.
			2—10	0.680	....	0.680	
August 26th, ‡ 1888	10.28 P.M.	10.42 P.M.	0—14 }	0.794	3.200	0.747	Very heavy shower with hail.
	10.42	10.50	0—08 }		0.350	0.047	Moderate rain.
			0—22	....	....	0.794	
September 16th, 1888	2.00 P.M.	2.50 P.M.	0—50 }	0.431	0.470	0.391	Heavy rain.
	2.50	3.15	0—25 }		0.100	0.042	Light rain.
			1—15	....	....	0.433	

* Average value; on west side depth was 0.818 inches, and on east side, 0.494 inches.

† Not uniform over territory.

‡ About one-fifth was hail, thus leaving depth of water equivalent to a rate of about 2.50 inches per hour. On the east side the depth of water precipitated was 0.711 inches when weighed on the morning of August 27th.

TABLE No. 4.

SHOWING duration of the maximum intensity of the principal rainfalls at Rochester, N. Y., from October 1st, 1887, to October 1st, 1888.

DATE.	Maximum intensity, inches per hour...	Duration of rain at maximum intensity. H. M.	REMARKS.
December 10th, 1887..	0.310	1 00	Preceded by two hours' light rain and followed by one and a half hours' light rain. Uniformly distributed.
April 5th, 1888........	0.240	0 30	Preceded and followed by light rain, lasting from one hour to one and a half hours. Uniformly distributed.
May 4th, 1888.........	0.300	0 13	Preceded by eight minutes' moderate rain and followed by twenty minutes' drizzling rain. Uniformly distributed.
May 9th, 1888..........	1.315 to 0.348	0 35 0 35	Sudden heavy shower, followed by drizzle lasting one hour. Direction from S. W. to N. E. Not uniformly distributed. In extreme eastern districts maximum intensity was only 0.35 inches per hour.
May 12th, 1888.......	0.300	0 30	Preceded by twenty minutes' moderate rain, and followed by ten minutes of light rain. Not very uniform.
May 26th, 1888.......	1.000	0 13	Preceded by short, heavy shower, and fifteen minutes' light rain, and followed by short, light rain and drizzle. Uniformly distributed.
June 2d, 1888.........	0.400	0 15	Sudden heavy shower, followed by fifty minutes' light rain and drizzle. Was a little heavier on west side.
June 24th, 1888.......	1.600	0 30	Sudden heavy shower No. 1, followed by twenty-seven minutes of light rain and drizzle. Apparently uniform.
June 24th, 1888......	2.620	0 20	Sudden heavy shower No. 2, followed by twenty-eight minutes of light rain. Apparently uniform.
June 28th, 1888.......	0.800	0 20	Preceded by sharp shower and forty-five minutes' light and moderate rain, and followed by ten minutes' light rain, and then by sharp shower. Apparently evenly distributed.
July 11th, 1888......	0.760	0 15	Preceded by twenty minutes' moderate rain. Not very uniform.
July 18th, 1888.......	0.750	0 10	Preceded by twenty-five minutes' light rain, and followed by forty-five minutes' moderate rain. Much heavier on west than east side.
August 4th, 1888.....	1.000	0 12	Sudden heavy shower, followed by one hour's moderate rain with light showers. Probably not very uniform.
August 16th, 1888....	1.616	0 15	Sudden heavy shower, followed by fifteen minutes' moderate rain; three hours' previously heavy rain. Not uniform.
August 17th, 1888....	1.333	0 10	Sudden heavy shower, followed by one hour's moderate rain. Rained some hours previously. Apparently uniform.
August 26th, 1888....	3.200 2.500	0 14	Sudden heavy shower with hail, followed by eight minutes' moderate rain. Fairly uniformly distributed. Deducting hail, rate would be about 2.5 inches.
September 16th, 1888.	0.470	0 50	Sudden heavy rain, followed by twenty-five minutes' light rain. Had rained some hours previously. Apparently uniform.

TABLE No. 5.

SHOWING the maximum flow and percentage of rainfall discharged during the period of such flow in the Clifford Street and Avenue B outlet sewer at Gauge No. 2, at intersection of Avenue B and Harris Avenue.

Tributary drainage area = 356.94 acres. Time required for passage of storm-waters through longest line of sewers above said gauge = 34 minutes, which should be increased by about ten minutes for concentration in sewers. Co-efficient of roughness: $n = 0.015$.

DATE.	Maximum Intensity of Rainfall.	Duration of Rain at Maximum Intensity.	Precipitation on Drainage Area.	Cross-sectional Area of Flow in Sewer.	Mean Hydraulic Radius (r) of such Area.	Adopted Slope (s) of Water Surface.	Co-efficient for Velocity (c)	Maximum Sewer Discharge (Q).	Percentage of Rainfall Discharged.
	Inches per Hour.	Minutes.	Cubic Feet per Second.	Square Feet.	Feet.		in $v = c\sqrt{rs}$.	Cubic Feet per Second.	
December 10th, 1887...	0.31	60	110.64	3.56	0.722	1/342	93.24	15.25	13.8*
April 5th, 1888...	0.24	30	85.67	2.44	0.580	"	88.90	8.94	10.4*
May 4th, 1888...	0.30	13	107.07	2.13	0.532	"	87.05	7.32	6.8*
9th, 1888...	1.315	35	469.48	13.73	1.186	1/400	103.00	77.01	16.4‡
12th, 1888...	0.30	30	107.07	2.97	0.653	1/342	91.15	11.83	11.0*
26th, 1888...	1.00	13	356.94	6.04	0.924	"	98.00	30.76	8.6*
June 2d, 1888...	0.40	15	142.76	2.23	0.547	"	87.70	7.81	5.5‡
24th, 1888...	1.55	30	553.20	7.53	1.005	"	99.80	40.72	7.4‡
24th, 1888...	2.62	20	935.10	10.16	1.106	"	101.80	58.82	6.3‡
28th, 1888...	0.80	20	285.52	7.53	1.005	"	99.80	40.72	14.3*
July 11th, 1888...	0.76	15	271.24	4.33	0.798	"	95.20	19.93	7.4††
18th, 1888...	0.75	10	267.68	4.43	0.807	"	95.45	20.53	7.6*
August 4th, 1888...	1.00	12	356.94	3.78	0.745	"	93.85	16.54	4.6‡
16th, 1888...	1.616	15	576.75	5.48	0.887	"	97.25	27.15	4.7‡
17th, 1888...	1.333	10	475.87	5.26	0.873	"	97.00	25.80	5.5‡
26th, 1888...	2.50	14	892.35	6.72	0.964	"	99.00	35.33	4.0†
September 16th, 1888...	0.47	50	167.75	6.41	0.946	"	98.55	33.25	19.8‡

* Preceded and followed by lighter rain.

‡ Sudden shower followed by lighter rain.

†† Heavy shower preceded by lighter rain.

† Intensity roughly estimated, deducting hail.

TABLE No. 6.

SHOWING the maximum flow and percentage of rainfall discharged during the period of such flow in the North Avenue sewer at Gauge No. 8, at the angle in North Avenue near Syracuse Street.

Tributary drainage area = 128.67 acres. Time required for passage of storm-waters through longest line of sewers above said gauge = 18 minutes, which should be increased by about eight minutes for concentration in sewers. Co-efficient of roughness : $n = 0.017$.

DATE.	Maximum Intensity of Rainfall.	Duration of Rain at Maximum Intensity.	Precipitation on Drainage Area.	Cross-sectional Area of Flow in Sewer.	Mean Hydraulic Radius (r) of such Area.	Adopted Slope (s) of Water Surface.	Co-efficient for Velocity (c)	Maximum Sewer Discharge. (Q)	Percentage of Rainfall Discharged.
	Inches per Hour.	Minutes.	Cubic Feet per Second.	Square Feet.	Feet.		in $v = c\sqrt{rs}$.	Cubic Feet per Second.	
December 10th, 1887...	0.31	60	39.90	3.68	0.630	1/600	77.70	9.27	24.1*
April 5th, 1888...	0.24	30	30.88	2.40	0.462	"	72.00	4.80	15.5*
May 4th, 1888...	0.30	13	38.61	2.64	0.496	"	73.25	5.56	14.4*
9th, 1888...	1.00 (?)	35	128.67	9.68	1.095	1/700	88.03	33.70	26.2†
12th, 1888...	0.30	30	38.61	2.80	0.518	1/600	74.00	6.09	15.8*
26th, 1888...	1.00	13	128.67	9.60	1.090	1/700	88.00	33.34	25.9*
June 2d, 1888...	0.40	15	51.48	2.36	0.455	1/600	71.80	4.67	9.0‡
24th, 1888...	2.62	20	337.19	19.50	1.406	1/900	92.45	71.26	21.1‡
28th, 1888...	0.80	20	102.96	8.28	1.017	1/600	86.65	29.54	28.7*
July 11th, 1888...	0.76	15	97.81	5.20	0.788	"	81.95	15.44	15.8††
18th, 1888...	0.75	10	96.50	4.32	0.701	"	79.80	11.78	12.2*
August 4th, 1888...	1.00	12	128.67	4.56	0.726	"	80.40	12.75	10.0‡
16th, 1888...	1.616	15	207.97	7.52	0.969	"	85.80	25.93	12.5‡
17th, 1888...	1.333	10	171.60	5.08	0.777	"	81.70	14.94	8.7‡
26th, 1888 ..	2.50	14	321.75	11.20	1.107	1/700	88.20	39.28	12.2‡
September 16th, 1888...	0.47	50	60.49	6.92	0.927	1/600	85.00	23.12	38.2‡

* Preceded and followed by lighter rain.
‡ Sudden shower followed by lighter rain.
†† Heavy shower preceded by lighter rain.
† Intensity roughly estimated.

TABLE No. 7.

SHOWING the maximum flow and percentage of rainfall discharged during the period of such flow, in the East Main Street sewer at Gauge No. 18, at intersection of East Main and Union Streets. Tributary drainage area = 25.12 acres. Time required for passage of storm-water through longest line of sewers above said gauge = 10 minutes, which should be increased by about six minutes for concentration in sewers. Co-efficient of roughness : $n = 0.017$.

DATE.	Maximum Intensity of Rainfall.	Duration of Rain at Maximum Intensity.	Precipitation on Drainage Area.	Cross-sectional Area of Flow in Sewer.	Mean Hydraulic Radius (r) of such Area.	Adopted Slope of Water Surface. (s)	Co-efficient for Velocity (c) in $v = c\sqrt{rs}$	Maximum Sewer Discharge. (Q)	Percentage of Rainfall Discharged.
	Inches per Hour.	Minutes.	Cubic Feet per Second.	Square Feet.	Feet.			Cubic Feet per Second.	
December 10th, 1887..	0.31	60	7.80	1.01	0.354	1/80	67.6	4.54	58.2 *
April 5th, 1888..	0.24	30	6.03	....	.....	"			
May 4th, 1888..	0.30	13	7.54	1.06	0.366	"	63.2	4.89	64.8 *
9th, 1888..	0.75 (?)	35	18.83	1.79	0.460	"	72.3	9.81	52.1 †
12th, 1888..	0.30	30	7.54	0.695	0.287	"	63.8	2.66	35.3 *
26th, 1888..	1.00	13	25.12	1.58	0.410	"	70.2	7 94	31.8 *
June 2d, 1888..	0.40	15	10.05	.....	.....	"			
24th, 1888..	2.62	20	65.81	3.30	0.560	"	76.2	21.04	32.0 §
28th, 1888..	0.80	20	20.10	1.395	0.415	"	70.4	7.09	35.2 *
July 11th, 1888..	0.76	15	19.08	1.53	0.432	"	71.2	8.01	41.2 ††
18th, 1888..	0.75	10	18.83	1.035	0.359	"	67.8	4.70	25.0 *
August 4th, 1888..	1.00	12	25.12	.....	.....	"			
16th, 1888..	1.616	15	40.56	1.815	0.463	"	72.5	10.01	24.7 ‡
17th, 1888..	1.333	10	33.47	1.26	0.396	"	69.6	6.17	18.4 ‡
26th, 1888..	2.50	14	62.80	3.30	0.560	"	76.2	21.04	33.5 §

* Preceded and followed by lighter rain.
‡ Sudden shower, followed by lighter rain.
†† Heavy shower, preceded by lighter rain.
† Intensity roughly estimated.
§ Sewer ran under head; figures given are for maximum discharge without head, previous to surcharge.

TABLE No. 8.

SHOWING the maximum flow and percentage of rainfall discharged during the period of such flow, in the Court and William Streets outlet sewer at Gauge No. 19, at intersection of Alexander Street and University Avenue. Tributary drainage area = 132.96 acres. Time required for passage of storm-water through longest line of sewers above said gauge = 15 minutes, which should be increased by about eight minutes for concentration in sewers. Co-efficient of roughness: $n = 0.017$.

DATE.		Maximum Intensity of Rainfall.	Duration of Rain at Maximum Intensity.	Precipitation on Drainage Area.	Cross-sectional Area of Flow in Sewer.	Mean Hydraulic Radius (r) of such Area.	Adopted Slope of Water Surface. (s)	Co-efficient for Velocity (c) in $v = c\sqrt{rs}$	Maximum Sewer Discharge. (Q)	Percentage of Rainfall Discharged.
		Inches per Hour.	Minutes.	Cubic Feet per Second.	Square Feet.	Feet.			Cubic Feet per Second.	
December	10th, 1887..	0.31	60	41.23	3.59	0.666	1/185	79.25	17.07	41.6 *
April	5th, 1888.	0.24	30	31.92	2.80	0.591	"	77.00	12.19	38.2 *
May	4th, 1888..	0.30	13	39.90	3.17	0.627	"	78.15	14.42	36.1 *
	9th, 1888..	0.75 (?)	35	99.75	5.41	0.787	"	82.15	28.99	29.0 †
	12th, 1888..	0.30	30	39.90	2.73	0.584	"	76.80	11.79	29.6 *
	26th, 1888..	1.00	13	132.96	4.80	0.750	"	81.35	24.86	18.7 *
June	2d, 1888..	0.40	15	53.20	3.99	0.715	"	80.50	19.97	37.5 ‡
	24th, 1888..	2.62	20	348.46	8.18	0.831	"	83.20	46.0	13.2 §
	28th, 1888..	0.80	20	106.40	6.67	0.841	"	83.40	37.52	35.2 *
July	11th, 1888..	0.76	15	101.08	4.37	0.725	"	80.80	22.09	21.8 ††
	18th, 1888..	0.75	10	99.75	3.22	0.634	"	78.35	14.77	14.8 *
August	4th, 1888..	1.00	12	132.96	4.03	0.701	"	80.25	19.88	15.0 ‡
	16th, 1888..	1.616	15	214.93	6.76	0.847	"	83.60	38.23	18.0 ‡
	17th, 1888..	1.333	10	177.29	4.22	0.715	"	80.50	21.12	11.9 ‡
	26th, 1888..	2.50	14	332.50	8.18	0.831	"	83.20	46.0	13.8 §

* Preceded and followed by lighter rain.
‡ Sudden shower, followed by lighter rain.
†† Heavy shower, preceded by lighter rain.
† Intensity roughly estimated.
§ Sewer ran under much head; figures given are for maximum discharge without head, previous to surcharge.

TABLE No. 9.

Showing the maximum flow and percentage of rainfall discharged during the period of such flow, in the Griffith Street sewer at Gauge No. 30, at intersection of Griffith Street and Broadway.

Tributary drainage area = 92.27 acres. Time required for passage of storm-water through longest line of sewers above said gauge = 16 minutes, which should be increased by about eight minutes for concentration in sewers.

Co-efficient of roughness: $n = 0.017$.

Date.	Maximum Intensity of Rainfall.	Duration of Rain at Maximum Intensity.	Precipitation on Drainage Area.	Cross-sectional Area of Flow in Sewer.	Mean Hydraulic Radius (r) of such Area.	Adopted Slope (s) of Water Surface.	Co-efficient for Velocity (c) in $v = c\sqrt{rs}$.	Maximum Sewer Discharge (Q).	Percentage of Rainfall Discharged.
	Inches per Hour.	Minutes.	Cubic Feet per Second.	Square Feet.	Feet.			Cubic Feet per Second.	
December 10th, 1887...	0.31	60	28.61	2.08	0.510	1/220	74.2	7.43	26.0*
April 5th, 1888...	0.24	30	22.15	1.48	0.425	"	70.9	4.61	20.8*
May 4th, " ...	0.30	13	27.69	2.16	0.519	"	74.5	7.82	28.2*
9th, " ...	0.75(?)	35	69.22	4.10	0.672	"	79.3	17.97	26.0†
12th, " ...	0.30	30	27.69	1.50	0.429	"	71.0	4.70	17.0*
26th, " ...	1.00	13	92.27	2.76	0.580	"	76.5	10.84	11.7*
June 2d, " ...	0.40	15	36.90	1.16	0.367	"	68.1	3.23	8.7‡
24th, " ...	2.62	20	241.83	6.00	0.750	"	81.2	28.45	11.8§
28th, " ...	0.80	20	73.84	5.86	0.745	"	81.1	27.66	37.4*
July 11th, " ...	0.76	15	70.14	3.28	0.621	"	77.9	13.57	19.4††
18th, " ...	0.75	10	69.22	2.02	0.502	"	74.0	7.14	10.3*
August 4th, " ...	1.00	12	92.27	3.12	0.609	"	77.4	12.71	13.8‡
16th, " ...	1.616	15	149.15	6.00	0.750	"	81.2	28.45	19.1§
17th, " ...	1.333	10	123.06	2.78	0.581	"	76.6	10.94	8.9‡
26th, " ...	2.50	14	230.75	6.00	0.750	"	81.2	28.45	12.3§
September 16th, " ...	0.47	50	43.38	3.76	0.653	"	78.8	16.14	37.2‡

* Preceded and followed by lighter rain.

‡ Sudden shower, followed by lighter rain.

†† Heavy shower, preceded by lighter rain.

† Intensity roughly estimated.

§ Sewer ran under head; figures given are for maximum discharge without head, previous to surcharge.

TABLE No. 10.

SHOWING the computed percentages of the heaviest rainfall discharged from five different city districts by the respective outlet sewers, during the period of maximum flow.

Date.			Maximum Intensity of Rainfall.	Duration of Rain at Maximum Intensity.	Percentages of Rainfall Discharged.				
			Inches per Hour.	Minutes.	District I, Gauge 2, Area = 356.94 Acres.	District IV, Gauge 8, Area = 128.67 Acres.	District X, Gauge 18, Area = 25.12 Acres.	District IX, Gauge 19, Area = 132.96 Acres.	District XVII, Gauge 30, Area = 92.27 Acres.
December	10th,	1887	0.31*	60	13.8	24.1	58.2	41.6	26.0
April	5th,	1888	0.24*	30	10.4	15.5	....	38.2	20.8
May	4th,	"	0.30*	13	6.8	14.4	64.8	36.1	28.2
	9th,	"	{ 1.315‡ to 0.75 (?) }	35	16.4	26.2	52.1	29.0	26.0
	12th,	"	0.30*	30	11.0	15.8	35.3	29.6	17.0
	26th,	"	1.00*	13	8.6	25.9	31.8	18.7	11.7
June	2d,	"	0.40‡	15	5.5	9.0	....	37.5	8.7
	24th,	"	1.55‡	80	7.4				
	24th,	"	2.62‡	20	6.3	21.1	32.0§	13.2§	11.8§
	28th,	"	0.80*	20	14.3	28.7	35.2	35.2	37.4
July	11th,	"	0.76††	15	7.4	15.8	41.2	21.8	19.4
	18th,	"	0.75*	10	7.6	12.2	25.0	14.8	10 3
August	4th,	"	1.00‡	12	4.6	10.0	....	15.0	13.8
	16th,	"	1.616‡	15	4.7	12.5	24.7	18.0	19.1§
	17th,	"	1.333‡	10	5.5	8.7	18.4	11.9	8.9
	26th,	"	2.50†	14	4.0	12.2	33.5§	13.8§	12.3§
September	16th,	"	0.47‡	50	19.8	38.2	....	....	37.2
Probable time required for concentration of flow at gauges: minutes......					44	26	16	23	24

* Preceded and followed by lighter rain.
‡ Sudden shower, followed by lighter rain.
†† Heavy shower, preceded by lighter rain.
† Intensity roughly estimated, deducting hail.
§ Sewer here ran under head; percentage is computed from maximum discharge without head, previous to surcharge.

DISCUSSION.

By Rudolph Hering, M. Am. Soc. C. E.

There is no doubt that all engineers who are engaged on municipal works are very much interested in the subject which has been so ably treated by Mr. Kuichling. Its importance is clear from the fact that if we make our sewers too large we spend more money than necessary, and if in built up cities we make them too small they are apt to cause considerable damage by flooding cellars. Therefore we are very anxious to know as nearly as possible the maximum quantity of rain-water for which provision is necessary. I have myself been particularly interested in the subject, and have often urged engineers to make experiments regarding the amount of rainfall entering sewers. Very little positive information is known about it either in our country or in Europe. There seems to be difficulty in convincing some municipal councilmen that the automatic rain-gauge, for instance, is anything but a costly scientific play-thing; that was an objection I heard made some years ago.

You will remember there was a committee appointed by the Society last year to urge upon Congress the importance of having the Signal Service Bureau use automatic rain-gauges in the principal cities, and a communication was sent to Washington asking for an appropriation of $2 000 for this purpose. This sum was not granted; but General Greeley has been enabled from his other funds to have some of these gauges erected, and I believe there are some working now.

He has also recently collected and published in the "Weather Review" the results of a large number of stray observations which show what heavy rainfalls we have in a very short duration of time. I thought before that a fall at the rate of 4 inches an hour was very rare, but I have come to the conclusion that we must have many storms with at least such intensity. I have here an extract from the "Review," in which I included rainfalls of over 3 inches in an hour, 2 inches in half an hour, and 1 inch in ten minutes.

In New York, Dr. Draper, of the Observatory at the Park, has kept an automatic registration since 1880, and from this I have taken the maximum intensity of storms for a few minutes, in order to determine the probable maximum quantity of water reaching the house drains.

If we reduce these amounts to a rainfall of inches per hour, we have four storms in New York City since 1880 which exceeded the rate of 4 inches an hour, continuing, at this rate, at least five minutes, two storms exceeding the rate of 6 inches an hour for at least three minutes, and one storm exceeding the rate of 7 inches an hour for two minutes. Four times within the last eight years has there been a fall at the rate of

5 inches an hour for at least five minutes, sufficiently long to allow the water from the roofs to get into the house drains.

Complaints have often been made to the Board of Health that the drains were too small and an investigation was made by the Department of Public Works to find out whether they were or not. The result indicated that 6-inch pipes draining a property having 25 feet front, laid at a grade of $\frac{1}{4}$ inch to the foot, were large enough to take a rainfall having the intensity of 6 inches per hour.

The Department of Public Works has made gaugings of the flow in a large sewer, but I regret to say that as the results have not yet been reported to the Commissioner, I am not able to give any details. But the large figures that Mr. Kuichling has arrived at are fully verified by the observations made here. It is certain that we have generally underestimated the quantity of water that comes into the sewers in our most populous cities.

The gaugings I refer to were made in a district of New York which is pretty densely built up. It has been found that three times during the last year, when the maximum rainfalls were not over .6 of an inch in ten minutes, more than 1 cubic foot per second per acre reached the sewer. That is considerably more than is given by the formulas we have been in the habit of using.

In connection with this work I tried to collect all the relative data that were available, and proceed somewhat on the method adopted by Mr. McMath in a paper read before this Society December 15th, 1886, by recording the elements of sewers that were, and those that were never, overtaxed by the heaviest rains. Then, by drawing a line between the plottings of the two results, we obtain the approximate capacity which the sewers ought to have. I have collated a number of such data, and arranged them in tabular form, which I think indicate very closely the maximum flow from the heaviest rains.

These results show that some of our sewers have been built too large, and others too small.

The Chair.—May I ask Mr. Hering if it is intended to publish the results of his experiments when they are completed ?

Mr. Hering.—They will be presented to Mr. D. Lowber Smith, Commissioner of Public Works and Member of the Society. In a conversation with him he said that the detailed matter would probably be a better subject for a paper to be presented to the Society than to print it in the Commissioner's Annual Report, as the public are not particularly interested in technical details of this nature.

I think there is one point in Mr. Kuichling's formula which presents a little difficulty. He introduces the element of time. Now, that is rather difficult to fix upon in practice. Recognizing this, I tried another plan, one which I thought more practicable, and that is by substituting the average slope of the ground. The diagrams are arranged

so that the ordinates represent the discharges, and the abscissas the drainage areas. The discharges from different areas having the same slope are united by one curve. For the same area it is seen that the greater the slope, the greater will be the discharge, so that the element of time is introduced in that way.

Maximum Rainfalls in short periods of ten minutes or less between January, 1880, and January, 1888, as recorded by the New York Meteorological Observatory.

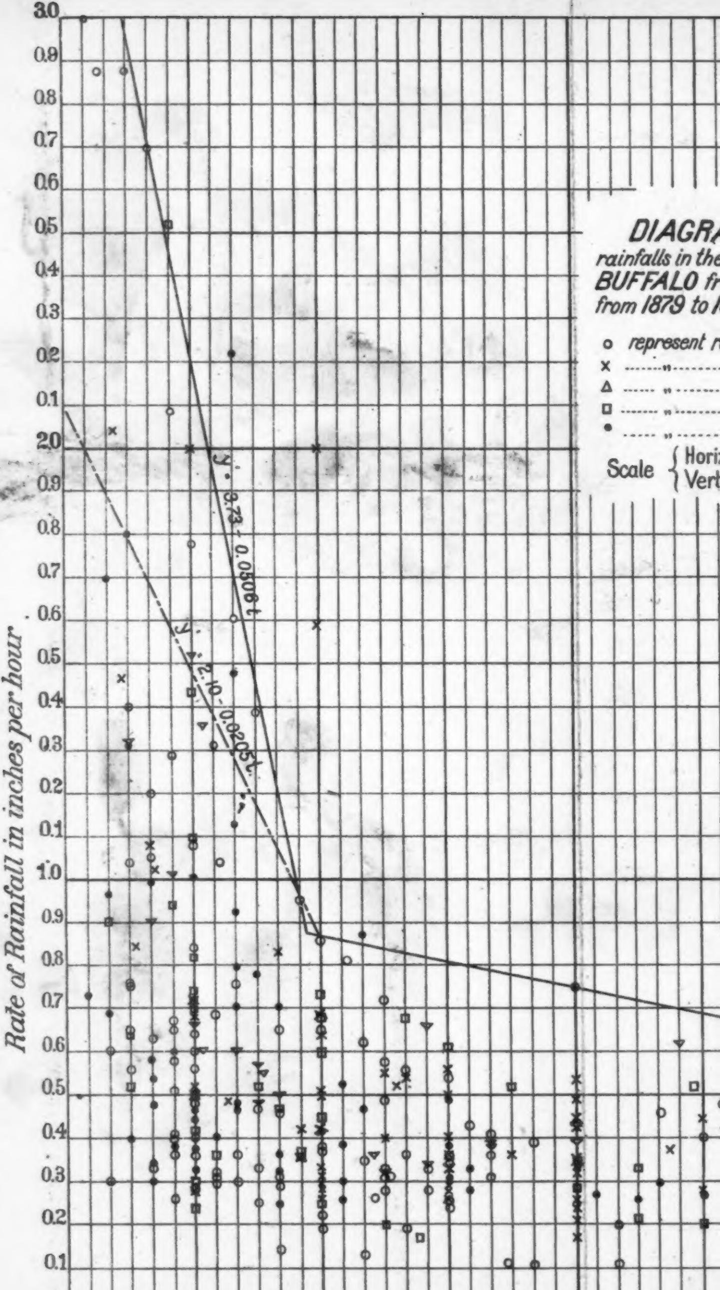
Date.	Max. fall in inches.	Time in minutes.	Date.	Max. fall in inches.	Time in minutes.
May 22d, 1881	1.15	.10	July 27th, 1880........	.50	.10
June 5th, 1885........	.30	.03	August 4th, 1888......	.59	.10
6th, 1883........	.44	.05	5th, 1884......	.45	.05
15th, 1882........	.35	.10	18th, 1887......	.43	.05
26th, 1888........	.45	.10	21st, 1888......	.40	.10
29th, 1882........	.50	.10	September 21st, 1882...	.45	.08
July 12th, 1884........	.40	.10	November 8th, 1888...	.19	.05
19th, 1888........	.39	.10	18th, 1886...	.25	.02

Maximum Rainfalls compiled from Monthly *Weather Review*, United States Signal Service, and published during the year 1888, having falls of:

3.0 inches in ....1 hour 0 minutes.
2.0 " .... 30 "
1.0 " .... 10 "
and over.

State.	City.	Date.	Amount in Inches.	Time Hrs. Min.
New Hampshire....	Auburn	August 27th, 1877.........	3.00	0.35
Massachusetts	Amherst............	July 16th, 1879...........	2.00	0.20
"	Boston.............	June 29th. 1879...........	2.00	0.30
"	New Lake...........	August 9th, 1878..........	6.50	3.00
Rhode Island.......	Providence.........	6th, 1878..........	4.49	1.00
"	"	6th, 1878.....	3.50	0.36
Connecticut	Southington	June 29th, 1879	1.45	0.15
New York..........	Albany.............	July 10th, 1876...........	1.22	0.10
New Jersey..........	New Brunswick	August 2d, 1887...........	4.50	1.00
Delaware............	Ft. Delaware	31st, 1868..........	3.00	0.50
Pennsylvania	Erie...............	June 17th, 1886.	1.02	0.15
"	Philadelphia	July 26th. 1887...........	0.62	0.07
"	"	August 3d, 1885..........	1.50	0.20
"	Hulmeville.........	25th, 1880.........	2.20	0.35
"	Wellsborough	21st, 1885.........	1.95	0.30
"	"	July 16th, 1880...........	1.78	0.25
"	"	June 19th, 1882	2.60	0.50
Ohio	College Hill	May 27th, 1888...........	2.38	0.30
"	Sandusky...........	July 11th, 1879...........	2.25	0.15
"	"	June 17th, 1881..........	1.90	0.30
"	Portsmouth........	22d, 1851...........	1.75	0.15
"	Grace	July 9th, 1888...........	7.00	2.00
"	Urbana.............	10th, 1879...........	2.00	0.25

STATE.	CITY,	DATE.	AMOUNT IN INCHES.	TIME HRS. MIN.
Indiana	Indianapolis	July 12tb, 1876	2.40	0.25
"	Logansport	7th, 1879	3.50	0.30
Illinois	Collinsville	May 23d, 1888	1.70	0.12
"	Bunker Hill	August 24th, 1882	3.20	1.30
"	Springfield	31st. 1881	3.18	1.00
"	Philo	July 8th, 1888	1.20	0.15
Michigan	Adrian	April 5th, 1888	1.50	0.10
"	Alpena	September 10th, 1884	1.05	0.11
"	"	June 24th, 1880	2.00	0.30
"	Detroit	August 31st, 1878	2.48	0.45
Iowa	Denmark	April 8th, 1882	1.87	0.30
"	"	June 25th, 1879	2.02	0.30
"	Cresco	July 21st, 1883	4.30	1.00
"	Amana	31st, 1878	1.56	0.15
"	Nashua	3d, 1882	2.00	0.30
"	Des Moines	June 24th, 1879	3.00	1.00
"	"	October 15th, 1880	2.30	0,30
"	Osage	August 26th, 1881	1.40	0.15
Nebraska	Clear Creek	July 7th, 1880	4.50	1.27
"	"	June 13th, 1879	2.00	0.25
"	"	25th, 1882	3.03	0.35
"	Ft. McPherson	May 25th, 1868	2.75	0.30
"	"	27th, 1868	1.50	0.05
"	Sidney Barracks	July 19th, 1875	4.00	1.30
Dakota	Huron	July 26th, 1885	1.30	0.10
"	Ft. Randall	June 28th, 1873	1.56	0.15
Missouri	St. Louis	September 19th, 1849	3.00	1.00
"	"	August 15th, 1848	5.05	0.15
Kansas	Ft. Riley	April 13th, 1885	2.70	0.45
"	Ft. Scott	October 2d, 1881	1.80	0.20
"	Ellinwood	August 20th, 1875	3.20	1.00
"	Dodge City	June 19th, 1888	3.24	0.45
Texas	Brownsville	October 23d 1884	1.20	0.06
"	Austin	May 7th, 1884	2.50	0.48
"	Galveston	June 4th, 1871	3.95	0.14
"	"	17th, 1888	2.00	0.30
"	"	February 27th, 1872	3.04	0.55
"	"	22d, 1888	3.31	1.00
"	"	November 2d, 1873	3.50	0.30
"	"	5th, 1877	1.48	0.15
"	"	October 30th, 1877	2.12	0.25
"	Mesquite	? 1875	3.38	1.00
"	"	August 11th, 1875	2.12	0.15
"	Nelson	September 30th, 1881	4.00	1.30
"	Rio Grande	May 29th, 1885	3.75	1.00
"	Embarras	28th, 1881	2.30	0.15
"	Pilot Point	April 28th, 1879	3.00	0.45
Mississippi	Vicksburg	November 15th, 1879	1.82	0.22
Alabama	Newmarket	September 4th, 1888	4.80	2.00
Tennessee	Knoxville	March 12th, 1878	1.08	0.15
"	Nashville	July 8th, 1878	2.90	0.48
"	Greenville	March 27th, 1885	2.00	0.15
West Virginia	Wellsburg	September 20th, 1883	4.50	2.15
Virginia	Keswick	June 3d, 1881	2.00	0.30
"	Wytheville	25th, 1875	2.70	0.44
"	Norfolk	August 20th, 1888	2.48	0.10
North Carolina	Elsworth	4th, 1880	9.00	3.30
"	Attaway	June 17th, 1876	2.00	0.30
South Carolina	Aiken	August 14th, 1878	4.00	1.00
Georgia	Savannah	21st, 1876	3.40	1.05
Florida	Jacksonville	20th, 1873	3.72	0.41
"	"	April 23d, 1883	1.50	0.20
"	"	July 6th, 1886	3.49	0.40
"	Biscayne	March 28th, 1874	4.10	0.30
"	Titusville	April 19th, 1888	1.78	0.25


DIAGRA
rainfalls in the
BUFFALO fr
from 1879 to
o represent r
×
Δ
□
•
Scale { Hori
Vert
Rate of Rainfall in inches per hour
$y = 3.73 - 0.0506\,t$
$y = 2.10 - 0.0205\,t$
3.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
2.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.
0ʰ
30
1ʰ
30
2ʰ
30

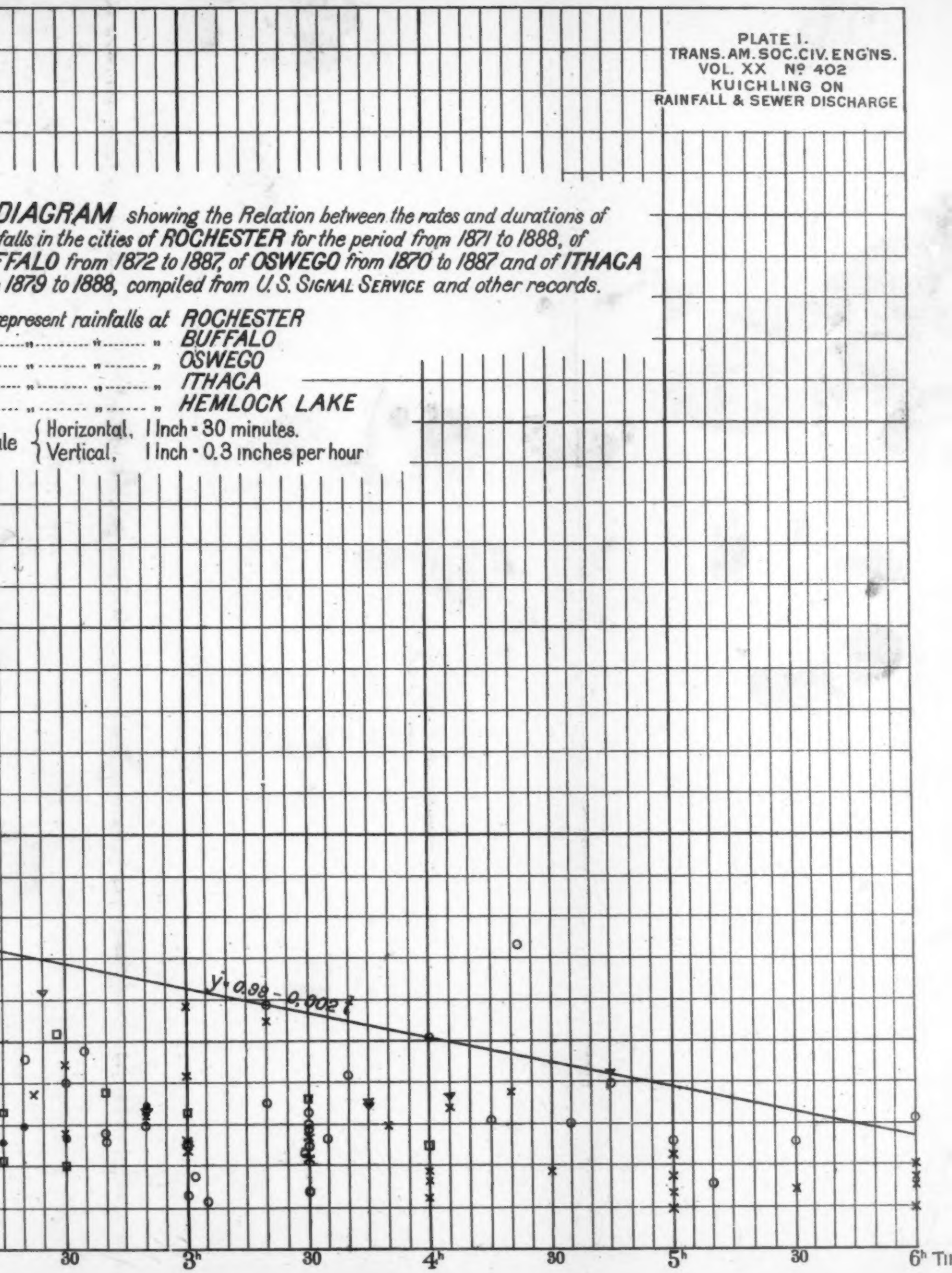


PLATE I.
TRANS. AM. SOC. CIV. ENG'NS.
VOL. XX Nº 402
KUICHLING ON
RAINFALL & SEWER DISCHARGE
DIAGRAM showing the Relation between the rates and durations of
falls in the cities of ROCHESTER for the period from 1871 to 1888, of
FFALO from 1872 to 1887, of OSWEGO from 1870 to 1887 and of ITHACA
1879 to 1888, compiled from U.S. SIGNAL SERVICE and other records.
epresent rainfalls at ROCHESTER
BUFFALO
OSWEGO
ITHACA
HEMLOCK LAKE
le Horizontal, 1 Inch = 30 minutes.
Vertical, 1 Inch = 0.3 inches per hour
y = 0.98 - 0.002 t
30
3h
30
4h
30
5h
30
6h Ti

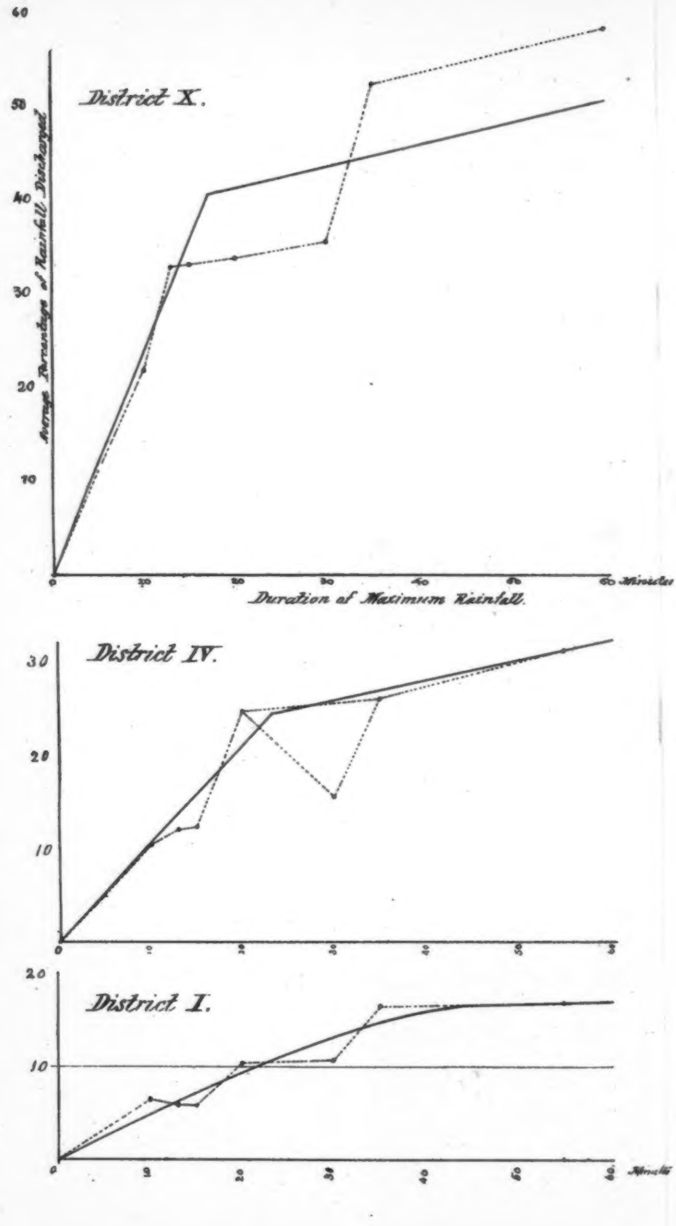
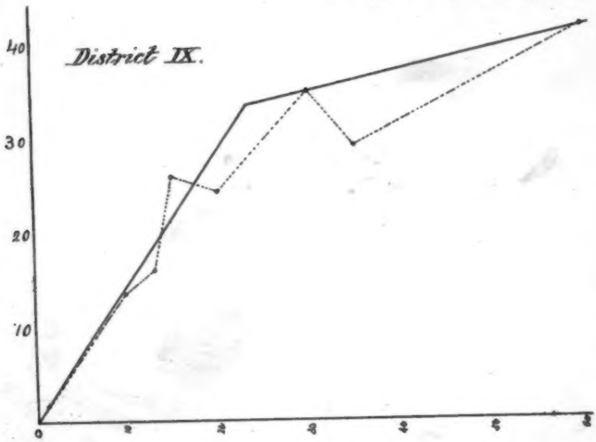
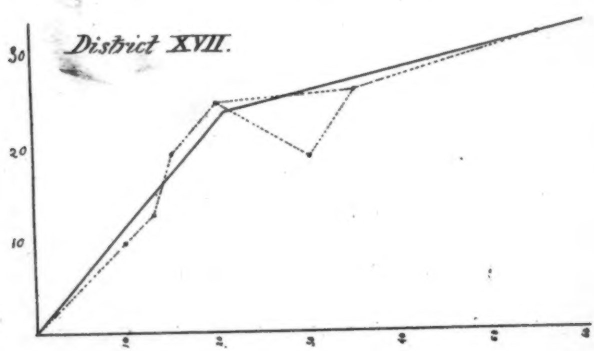

District X.
Average Percentage of Rainfall Discharged
Duration of Maximum Rainfall.
Minutes
District IV.
District I.
Minutes

PLATE II.
TRANS. AM. SOC. CIV. ENG'NS.
VOL. XX Nº 402
KUICHLING ON
RAINFALL & SEWER DISCHARGE.





Diagrams showing Relation of Maximum Sewer Discharge to duration of Rainfall on Five different Drainage areas in Rochester, N.Y.